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The Electric Motor

AND ITS APPLICATIONS.

BY

THOMAS COMMERFORD MARTIN

AND

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MEMBERS AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.



WITH TWO HUNDRED ILLUSTRATIONS.



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PREFACE.

NO department of applied electricity has undergone greater development during the last two years than that which concerns the use of electricity as a motive power. In America, a remarkable interest in the subject has been manifested, leading from mere experiment in the laboratory to practical work and the opening up of a new occupation for electricians. As a result, several thousand motors are now in successful operation all over the country, while on numerous street railways electricity has become the sole agency of locomotion.

Under these circumstances, it is natural that a demand should arise for books dealing with the principles involved in the use of dynamo-electric machines as motors, and giving some account of the most noteworthy and important types. With the object of meeting the want, the authors have prepared this work. It is based largely upon the articles that they have contributed to *The Electrical World* or that have been translated and reproduced by them in that journal from a variety of foreign contemporaries. In their original plan, it was intended to give far more space to earlier motors than has now been devoted to them; but in view of the fact that so much activity has been displayed in the motor field during 1886, and that all the standard works on dynamo machines include the older and better known motors, it has been thought wise to treat of the modern motor with the utmost fulness possible, even at the expense of the theoretical and historical parts of the work. The nature of the contents has, therefore, been slightly changed since the book was taken in hand, but only, it is hoped, with an increase in its immediate value and usefulness.

In addition to revising and rewriting their own articles, the authors have in a few instances availed themselves of contributions to *The Electrical World* by Mr. C. O. Mailloux and Mr. N. S. Keith, as well as of a special analysis of motor patents, prepared for the same journal by Mr. F. B. Brock. They are also under many obligations for assistance rendered by motor inventors and designers, and may here thank Mr. Leo Daft, Mr. Frank J. Sprague, Mr. Stephen D. Field, and Mr. C. J. Van Depoele for special facilities. They have, moreover, had frequent occasion to consult the electrical and other scientific publications of Europe, including *La Lumière Electrique*, *L'Electricien*, *La Nature*, the *Elektrotechnische Zeitschrift*, the London *Electrician*, the London *Electrical Review*, the *Mechanical World*, *Engineering*



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THE ELECTRIC MOTOR

AND ITS APPLICATIONS.

CHAPTER I.

ELEMENTARY CONSIDERATIONS.

As the functions of the electric motor are dependent upon the action of the electric current, it is necessary at the beginning of the present work to give a review, however brief, of the principal facts involved.

The time is not so very remote when the existence of an electric current was chiefly, if not wholly, made manifest by effects other than magnetic. Up to the year 1820 one of the most important facts generally known was that if the circuit from a voltaic battery was completed through acidulated water, the water was decomposed. Another interesting thing ascertained was that if a conductor were made sufficiently thin, the current would bring it to incandescence. To these, we may add the discovery of the electric arc by Sir Humphry Davy during the first decade of this century, and that of the reaction of the muscles and nerves to the passage of a current.

For many years the idea had prevailed, as Prof. Forbes puts it, that there was some "hidden connection between the compass and electricity, between the power that impelled the compass to point to the north and the lightning in the sky. It had been believed that when lightning had disarranged the compass-needle and reversed its polarity, it showed that there was some connection between electricity and magnetism." What this connection was long remained a matter of mere speculation, but while carrying on some experiments with the object of solving the problem, Oersted found that when the current from a galvanic cell was passed through a wire held over a compass-needle from the south to the north, the needle's north pole was swerved to the west; see Fig. 1.

Thus, practically, was demonstrated for the first time the correlation between electricity and magnetism. The experiment attracted universal attention, and gave to many investigators a clue to follow up. It was not long after this in the same year, 1820, that Arago and Davy discovered, independently of each other, that iron and steel could be magnetized by the passing of a current through a wire wound around them; and Sturgeon was prompt to apply the principle to the construction of powerful electro-magnets.

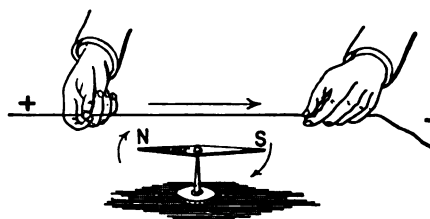


FIG. 1.—OERSTED'S EXPERIMENT.

It was also noted by Barlow, that by passing a current from the centre to the circumference of a copper disc placed between the poles of a magnet, the disc would revolve. This, familiar as "Barlow's wheel," was the first electric "motor," in the true sense of the word.

Faraday, in 1831, recognizing with the insight of genius, the relation and convertibility of the phenomena so far observed, obtained an electric current by electro-magnetic induction. This grand discovery may be summarized in the statement that when a conductor in closed circuit is made to cut magnetic "lines of force," a current is generated in that conductor. Far-

aday also reversed Barlow's experiment and obtained a current from a copper disc rotated between the poles of a magnet. But he left the application of the fruitful laws he had discovered to others, who invented numerous types of magneto-electric generators, into a description of which it is not needful here to enter.

Although the reversibility of the electric motor and the magneto-electric generator had already been noticed, little thought, apparently, was given to the fact; and meantime the other phenomena exhibited in the action of electro-magnets were employed in the construction of electric motors, some of which are described in subsequent chapters.

It was not until 1873, after the substitution of electro-magnets for permanent ones in electric generators, that the reversibility of the "dynamo" was fully recognized or realized, in the action of the Gramme machines exhibited at the Vienna exhibition of that year. As said above, electric motors had been built and operated many years before this, but they found no extended practical application, chiefly because they depended upon the galvanic battery for a supply of current. Now, as the energy developed by the oxidation of a quantity of zinc of a given value in a battery is far less than that which can be obtained by burning a quantity of coal of the same value under a steam boiler, it follows that electric motors could not compete with other forms of motors. Hence it remained for some cheaper source of current to be discovered, as it was in the dynamo-electric generator.

With this brief sketch, intended to be suggestive rather than exhaustive, of the facts relating to the evolution of the electric motor of to-day, we come to consider the motor in regard to the manner in which it operates as a machine for converting electrical energy into mechanical energy.

Beginning with the earlier forms of motors, we note at once several ways in which the current can be applied for mechanical purposes. The term "electric motor," it should be premised, includes all apparatus by which energy in the form of electric current is converted into mechanical energy, through whose employment work is performed, such as the driving of a fan or a lathe, the raising of an elevator, the propelling of a locomotive, and the like. Thus we

may use the attraction that an electro-magnet exerts upon an iron or steel armature; or the mutual attraction between two electro-magnets. These and analogous principles are evidently based upon the attractive force exhibited between masses of magnetic metal.

In the practical, commercial motor of to-day, however, the action, though apparently similar to the above, is quite different. It depends upon the principle that when a current passes through a wire, the latter becomes surrounded by a field of force similar in nature to that pertaining to "permanent" magnets. This is clearly shown in Fig. 2, which represents a plate through which two wires pass, the lines of force being exhibited by the positions assumed by the iron filings sprinkled upon the

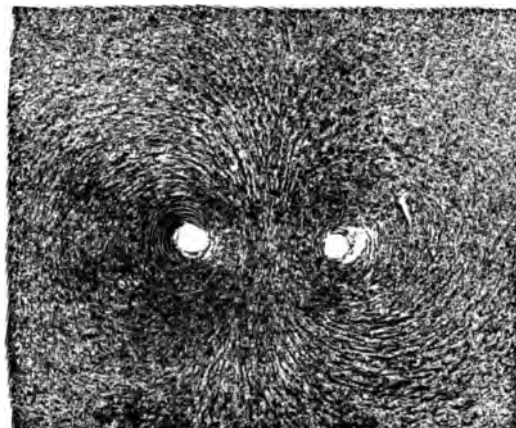


FIG. 2.—FIELD OF FORCE AROUND TWO WIRES.

surface of the plate. As will be observed, the lines of force encircle the wire, and when such a wire is brought into the vicinity of a magnet, it acts to all intents and purposes as if it were a magnet having circular lines of force at all points in planes at right angles to its length.

Now, if the current in the wire is in a certain direction, these lines of force will appear to circulate from left to right; and with the current in the contrary direction, from right to left. The wire in this condition, when brought in proximity to a magnet, is attracted or repelled in the same way as if it were a magnet, the attraction or repulsion being determined by the direction in which the lines of force circulate—in other words, according to the direction of the current.

The action, then, in the majority of electric motors of to-day is primarily that exhibited between a magnet and a wire carrying a current, and is the reverse of the action seen in the magneto-electric or dynamo-electric machine. In the magneto and dynamo, the motion of a conductor generates current; in the former, a current in the conductor produces motion. In the dynamo, it requires mechanical power to force the wires through the magnetic field, in order to generate current, and, according to Lenz's law, the currents generated have a direction such that their reaction upon the magnet tends to stop the motion which produces them. Conversely, in the motor it is the current acting upon the magnet that produces mechanical power. In this case, however, the reactions of the current being free to exert their power, the motion obtained will be the opposite of that in the dynamo. Hence we understand why a dynamo set to work as a motor, runs in the reverse direction, where the construction of the machine is such that the polarity of the field magnets remains the same in both functions of generator and motor.

It was said above that the action in nearly all the motors of to-day is due primarily to the reaction between magnet and current, in contradistinction to that exhibited in the older motors, which operated by the attraction of magnetized iron or steel. But as the modern motors have iron in their armatures, the question may be asked, What is the object in putting it there? The answer is, that by the presence of the iron the magnetic lines of force are strongly concentrated upon the wires. Dynamos will generate current and motors will perform work without the presence of an iron core in their armatures, but both are less efficient when so constructed.

Let us now see what takes place when the electric motor starts to work. We will suppose, for the sake of simplicity, that a galvanic battery is connected with a motor, and that a galvanometer is interposed in the circuit. If now we clamp the motor down so that it cannot revolve, and hence cannot do work, we get a certain strength of current. If we then release the motor so as to allow it to revolve, we find that as the speed of the armature increases, the current decreases. This fact was observed by the earliest experimenters with electric motors, and not being correctly interpreted was consid-

ered one of the greatest drawbacks to successful operation, for it was believed at that time that as the motor revolved it created a resistance which tended to diminish the current. It was argued, therefore, that the electric motor was necessarily a wasteful machine. We know to-day that this is by no means the case, and that the action observed in the electric motor is one upon which its true value as a working and useful machine depends. Jacobi was the first to point out that the diminution of current indicated by the galvanometer was not due to resistance engendered by the motor, but was due to a counter-electromotive force generated by it. This is easily understood when we consider that the motor, in revolving in a direction opposite to that of the generator, creates a current in the other direction. The opposing current, of course, lessens the original current. We may here appropriately and correctly apply the converse of Lenz's law above quoted, and say that the motion produced is always such that by virtue of the magneto-electric induction which it sets up, it tends *to stop the current*. From his observations, Jacobi formulated the important law that when an electric motor does its greatest possible work, it diminishes the original current one-half; and hence a loss of 50 per cent. is experienced when the motor is exerting its greatest power.

This can be shown by a simple illustration. Let us take two machines exactly alike and connect them up as generator and motor, the former being driven at a constant speed. Now, if while the generator is at work we clamp the motor so that it cannot revolve, no work is being done by it, and, at the same time, no counter-electromotive force is generated. If now we release the motor, and allow it to revolve freely, its speed will gradually increase until reaching that of the generator. But at this equal speed it will create a counter-electromotive force equal to that of the generator, so that, practically, there will be no current at all, and, evidently, the motor will again be incapable of doing work. We see, therefore, that at zero counter-electromotive force and at maximum counter-electromotive force, the motor does no work. The mean between these two limits is one-half the original electromotive force; so that, as Jacobi pointed out, the motor is doing its greatest work when the original current is reduced one-half, *i. e.*, when the coun-

ter-electromotive force is 50 per cent. of the original electromotive force.

But this law, relating only to the maximum *work* or *activity* of the motor, has unfortunately been misinterpreted to mean that the maximum efficiency of the electric motor is 50 per cent., thus making it appear to be a comparatively inefficient and wasteful machine.

The *efficiency* of the electric motor can, theoretically considered, be made to include anything between 0 and 100 per cent. In order to make this clear, we will take the same example as before. It has been seen that when the generator is in operation and the motor is clamped down, the latter does no work, and the current is dissipated and wasted in heating the circuit. Hence the efficiency, being the ratio of the power applied in the generator to that obtained from the motor, is zero. It has also been seen that when the motor is running without a load, it generates a counter-electromotive force equal to the original electromotive force, and reduces the current in the line to zero. But, evidently, with no current existing it requires no power, excepting that for overcoming friction, to drive the generator. We thus have virtually no power required at the generator and virtually none developed at the motor—which gives an efficiency of 100 per cent. This, as we have seen, takes place when the counter-electromotive force is 100 per cent. of the original.

Now let us put a small load upon the motor. Its speed, which has hitherto been equal to that of the generator, will be diminished in consequence, and hence the counter-electromotive force will fall off. This allows a certain amount of current to flow through the circuit, and the generator requires a certain corresponding amount of power to drive it. If we go on increasing the load of the motor, we reduce, in equal degree, the speed and the counter-electromotive force, while increasing the current and the power necessary to energize the generator. Each accession of current, therefore, means more power applied to the generator. But while at 100 per cent. efficiency both machines were running at the same speed, the increase in load on the motor has checked its speed, and hence it is not doing as much work as is required to run the generator, which retains its original speed. It follows that the efficiency can no longer be 100 per cent., but must be something less; and that something

less is clearly the ratio between the relative speeds of the generator and the motor.

Now it has been seen that the counter-electromotive force is in direct ratio to the speed of the motor. We infer, therefore, that the efficiency of an electric motor is in direct ratio to the counter-electromotive force developed. If we run a motor so as to allow it to develop a counter-electromotive force of 90 per cent., its efficiency will be 90 per cent.; and thus we can, by reducing the power developed by the motor, increase its efficiency to any desired degree. It being true also that in order to obtain the maximum *power* from a motor we reduce its efficiency to 50 per cent. it is evident that when we wish to work with higher economy we must not tax the motor to its full working capacity.

As these principles are new to many, we have sought, even at the risk of making a labored and reiterative explanation, to state them fully. A very apt analogy is encountered in the working of the steam engine, with which greater familiarity exists. By letting the valve of an engine follow full stroke, one might admit steam to the cylinder at boiler pressure during the entire stroke. This would give a mean effective pressure upon the piston equal to the boiler pressure and would cause the engine to exert its greatest power. But this method of operating is not economical, and in actual practice, the steam is cut off at different points in the stroke. That of course reduces the mean effective pressure, and hence the power of the engine below that which it could be made to exert if run uneconomically.

As just said, we have entered with careful explicitness into the description of the action involved in the operation of the electric motor, because considerable misapprehension appears to exist as to the true meaning of Jacobi's law. We have refrained, as will be noted, from any mathematical demonstration of these important facts and principles, for the reason that to many deeply interested in this subject, mathematical symbols and formulæ furnish no adequate picture of the reasoning involved.

In describing the causes of the efficiency of electric motors, we have assumed that the generator and motor are both perfect converters of energy; that is, that the generator is capable of converting into electricity all the power applied to it, and that the motor is capable of convert-

ing into mechanical power all the electricity supplied to it (friction being omitted in both cases). Now in actual practice such is not the case, because all dynamos present resistance to the current, which generates heat in them; and other causes besides friction tend to reduce the efficiency of the machine. Dynamos have nevertheless been built giving an efficiency of over 90 per cent., showing that they are excellent converters of energy.

But it has been found in the past that when efficient dynamos were employed as motors their efficiency was reduced considerably. This difference was generally sought to be explained by an assertion or a supposition

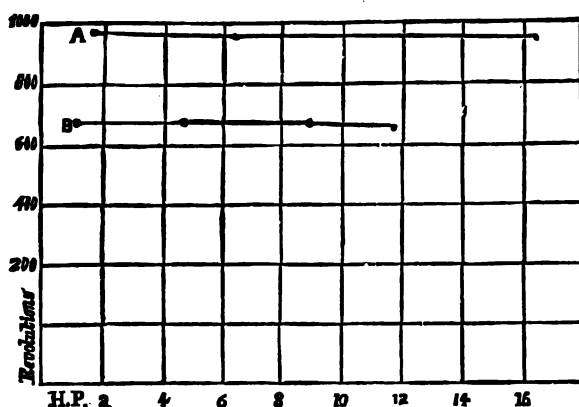


FIG. 3.—DIAGRAM SHOWING CONSTANCY OF SPEED UNDER VARYING LOADS.

that, having been designed and made for one purpose, the machine was, therefore, not suitable for the other. No satisfactory explanation was given of the cause of this lower efficiency of motors, or, in other words, of how the missing power is expended.

Taking up this question Mr. Mordey, an able English electrician, has recently shown the principal cause of this loss, which can be readily avoided, and his experiments also establish the fact that a well constructed motor approaches very closely in its action the limit that theory would assign, as indicated above. In the search for general principles, says Mr. Mordey, all those ways of considering the actions which depend on the idea of magnetic poles in the armature were abandoned, and the conclusion was arrived at that the armature should have no polar action whatever, that the iron of the armature should have only the function of a conductor of lines of force, and that the power

of the motor should be due to the simple action between the lines of force of the magnetic field and the armature wires conveying currents at right angles to those lines of force. This mode of regarding motor action is convenient on several grounds, and leads to certain conclusions, which, if correct, form substantial bases for practical construction. Thus the armature, instead of being, as hitherto, considered as a strong electro-magnet placed in the field of another electro-magnet, is to have its electro-magnetic functions reduced as much as possible, or preferably suppressed altogether. The field is to be very strong.

As with such an arrangement there is no polar effect in the armature except that due to the direct magnetic induction of the field-magnets, it follows that the maximum power is obtained with any given current when the brushes occupy an absolutely neutral position, or, in other words, when there is no "lead" and no distortion or rotation of the field. These conditions do away with the most troublesome and prolific cause of the sparking at the brushes.

But by working backward in this way, Mr. Mordey saw that the conditions which seemed to be best for a motor were precisely those which the would-be designer of a perfect dynamo would set before him as his goal.

Certain perfect analogies had been arrived at. In both dynamos and motors, according to this briefly sketched view: (1.) The field should be a very strong, the armature a very weak, electro-magnet. (2.) In both generators and motors "lead," distortion, or displacement of brushes or of magnetic field is wrong, and is to be avoided by attention to (1). Whatever "lead" there may be in either case, there is this difference, that in dynamos this "lead" is in the direction of rotation; in motors it has the opposite direction, as the course of the current through the armature is reversed, but the field is the same. (3.) In both generators and motors absence of sparking at the brushes depends mainly on the conditions of (1) being complied with. (4.) Reversal of rotation. In neither generators nor motors is movement of the brushes necessary.

But having got so far, a little consideration suggested the probable existence of another analogy. Since a dynamo, having the above theoretically perfect form and action, with a constant field, would produce a constant elec-

tromotive force if run at a constant speed, independently of the load or amount of current generated, a motor constructed on the same principles and having a constant field, if supplied with energy at a constant difference of potential, should run at a constant speed, independently of load.

If this should prove to be a true analogy, a simple means of obtaining results of great use in the practical application of electricity would be obtained.

The experiments were carried out with a "Victoria" dynamo. The results ultimately obtained, which are given in the following tabulated account of the experiments, and in the curves plotted from them, show that this fifth analogy is as true as the preceding ones, a constancy of speed being obtained that was very remarkable, even when the load was increased, until much more than that which, as a generator, was usually considered the full working current was traversing the armature.

Two sets of readings were taken, working up to about the same current in each set, but with the potential-difference of the supply different in the two cases, as stated. The field was of the same strength throughout. The load consisted of another "Victoria" dynamo driven through a modified White's transmission-dynamometer, the work being varied as required by altering the external circuit of this dynamo.

At first it appeared that the counter-electromotive force of the motor was dependent neither on speed nor strength of field, as the latter was constant and the former very nearly so, while the current rose with the work; but calculation showed that this was not the case; indeed, it could not be so.

Calling the counter-electromotive force e , and the loss of potential caused by the resistance of the armature e_1 , and the difference of potential at the terminals E , then

$$e + e_1 = E.$$

Calling the current C , and the resistance of the armature R , we know that

$$e_1 = C R.$$

The resistance of the armature of the motor in question was .027 ohm, which we call .03 in order to make some allowance for the effect of heating.

Experiments with a D₂ "Victoria" Shunt Motor at Constant E. M. F.

Speed.	Current.	Difference of potential at terminals.	H. P.*	
975	36.3	140	1.8	Curve A. Maximum speed-variation 3 per cent.
965	66.5	140	6.6	
948	97.1	140	12.87	
945	130.8	140	16.3	
680	29	100	1	Curve B. Maximum speed-variation 3 per cent.
677	61.4	100	4.8	
675	102	100	9.14	
660	125	100	11.7	

* Including an unascertained loss in transmission.

In the first and last readings of the second set of tests (curve B) Fig. 3, we have, therefore, the following conditions:

Speed.	e_1 .	e .
680	.87	99.13
660	3.75	96.25
Now		
	680×96.25	
	$\frac{\quad}{660} = 99.13.$	

From which it appears that the counter-electromotive force was exactly proportional to the speed, as is to be expected where the field is constant and the magnetic distortion *nil*.

The other cases do not work out with the same accuracy. The results are, however, quite within the limits of error inseparable from the rather rough conditions of workshop tests.

One other fact may be pointed out in connection with these tables of results and curves. In the case of dynamos working with a constant field, the output with the same current is almost exactly proportional to speed, as the electromotive force is also simply proportional to speed. So with the motor, the speed is proportional to the electromotive force of supply, and the work, with the same current in the two cases, is simply proportional to speed, therefore, to electromotive force.

Turning now to the question of the efficiency above alluded to, in order to localize the loss which was found to occur in motors and to ascertain its cause, the several possible sources of waste were carefully considered. These are: (a.) Friction at the bearing, air friction, and friction of the brushes against the commutator. (b.) Loss of energy in heating the armature

and field-conductors, and a certain loss due to self-induction. (c.) Loss by the production of eddy currents in the iron.

Now it is evident especially with a generator or motor having the qualities sketched above, that at the same speed, and working with the same currents in its conductors, the losses under (a) and (b) must be identical, whether it be working as a generator or as a motor. And as with such conditions its efficiency as a motor is lower than as a generator, the cause of the loss must be sought under (c), *i. e.*, the eddy or Foucault currents in a dynamo must be less than in a motor, all other conditions being the same. And such is the case, the explanation arrived at by Mr. Mordey being a very simple one.

To quote again from Mr. Mordey, in a dynamo the rotation of the armature causes eddy currents to be generated in the iron core, in the same direction as in the conductor proper with which the core is surrounded. Of course, as the armature is always more or less subdivided or laminated in a direction at right angles to the lines of force, any circulation of currents round the core is avoided, but local currents, which are aptly called eddies, are set up, and, taken as a whole, these eddy currents on the outside of the core are in the same direction as the current flowing in the copper conductors.

In an electric motor, however, the eddy currents and the currents in the copper conductor are in opposite directions; as, although the electromotive force set up in the conductor is in the same direction in a motor as in a dynamo, the current in the former is forced through the armature in a direction contrary to the electromotive force, or opposite to its course in a generator. According to the laws of induction, therefore, it will be seen that while in a dynamo the two sets of currents, those in the iron

and those in the conductor, tend to oppose and reduce one another, in a motor they act in such a manner as to mutually assist each other. Thus, with the strength of field, the current in the conductor, and the speed, the same in the two cases, it will be seen that in a motor the eddy currents in the iron core of the armatures will be greater than in a generator, and therefore the heat lost in the former will be more than in the latter. There is little doubt that this is the cause of the efficiency of motors being lower than that of generators; and it points to the advisability of giving more attention in the former to those principles which are well understood for the reduction or elimination of eddy currents.

This precaution to be observed was first pointed out by Mr. Mordey but had been recognized by others, and is of the greatest importance. We have personally seen the results of experiments upon small motors which with solid iron cores gave an efficiency of only 20 per cent. but with laminated cores were brought up to 70 per cent. efficiency.

Regarding the difference which should exist between a dynamo and a motor, Profs. Ayrton and Perry have advanced the theory, that in the dynamo the field magnets should be large and strong and the armature small and weak magnetically, while the contrary applies in the case of the motor. Practice, however, does not bear out this assumption, for only recently Dr. John Hopkinson in some tests of identical machines of his design, run respectively as dynamo and motor, obtained almost identical efficiencies.

We may conclude, therefore, that there is no radical difference in the relative actions of motor and dynamo and that the losses which have heretofore been experienced were due to faultiness in internal construction.

CHAPTER II.

EARLY MOTORS AND EXPERIMENTS IN EUROPE.

THE first experiments with electric motors to attract general attention throughout Europe appear to have been those of Jacobi, from 1834 to 1838, although prior to that time the field had been boldly entered by other acute investigators, who sought in various and ingenious ways to utilize the principles we have outlined in the preceding chapter. Thus in 1826, Barlow showed how to employ electricity as a continuous motive power by rotating a disc of copper between the poles of a magnet. The current was sent perpendicularly through the disc from its axis to circumference, when it passed into a cup of mercury. In 1830, the Abbè Salvatore dal Negro, professor of natural philosophy at the University of Padua, made a motor in which a permanent magnet oscillated between the legs of an electro-magnet, the polarity of the limbs changing at each movement. The oscillation was converted into continuous rotation.

In 1832, before the Zurich Society of Engineers, Dr. Schulthess suggested that "a force such as we obtain by interrupting the current and establishing it again could be advantageously applied to mechanics," and in 1833 he exhibited to the society a machine in which his ideas were embodied. About this time, too, Botto is said to have invented a motor in which a lever worked like that of a metronome, by the alternate action of two fixed electro-magnetic cylinders on a third movable cylinder attached to the lower arm of the lever. The upper arm imparted a continuous circular movement to a metal fly-wheel.

Thanks to the substantial aid of the Emperor Nicholas of Russia, who contributed a sum of \$12,000 to the work, Professor Jacobi, the discoverer of electro-plating, was enabled to prove in 1838, at St. Petersburg, on the Neva, that his electro-magnetic motor of 1834, as improved, could replace the oarsmen in a boat carrying a dozen passengers. Fig. 4 is a perspective of the Jacobi motor of 1834, which was composed

of two sets of electro-magnets. One set was fastened to the square frame *T*, disposed in a circle and with the poles projecting parallel with the axis. The other set *S* was similarly fastened to the disc *A* attached to the shaft and revolving with it. Each set comprised four magnets, and there were consequently eight magnetic poles. The current from a powerful battery passed through the commutator *C* to the coils of the electro-magnets, and as the magnets attracted each other the disc rotated. By means of the commutator on the shaft, the current was reversed eight times during each revolution, just as the poles of two sets of magnets arrived opposite each other. Attraction ceasing, repulsion took place, and the motion was thus accelerated. As the poles were alternately of different polarity, the reversals had the effect of causing attraction between each pole of one set and the next pole of the other. In his historic experiments of 1838, Jacobi used a modified form of this motor, so as to obtain greater power. In the new form, two sets of electro-magnets were attached to stationary vertical frames, one on each side of a rotating disc or star. Each set was composed of twelve electro-magnets. The electro-magnets on the rotating star were made in the form of bars passing entirely through the star. The axis carried a commutator formed of four wheels, regulating the direction of the current with the result that when the straight bar magnets were between two consecutive poles of the horse-shoe-magnets on the frames, they were always attracted towards the one and repelled from the other. The reversal of the current took place when the rotating poles were exactly opposite the fixed ones. The boat upon which this motor was placed, and which it propelled by means of paddles on the Neva, was 28 feet long, 7 feet wide, and 2 feet 9 inches draught. No fewer than 14 passengers were carried. The battery power was furnished by 320 Daniell cells, the weight of which was far from incon-

siderable. In 1839, on a repetition of the experiment, 138 Grove cells were used. At no time was a higher speed attained than 3 miles per hour.

At this time, 1838-9, an inventive Scotchman, named Robert Davidson, had built a lathe and a small locomotive for which electricity was the driving power. The motor for the locomotive consisted of two cylinders of wood fitted to

magnet. By this arrangement, it followed that the current was interrupted in the active electro-magnet and sent into the other, its *vis-a-vis*; and thus the axle was continuously turned. Acting together, the four sets of armatures and the two axles served to propel the car. Two sets of cells were employed, one for the electro-magnets on the right and the other for those on the left. At each extreme end of the axles, in-

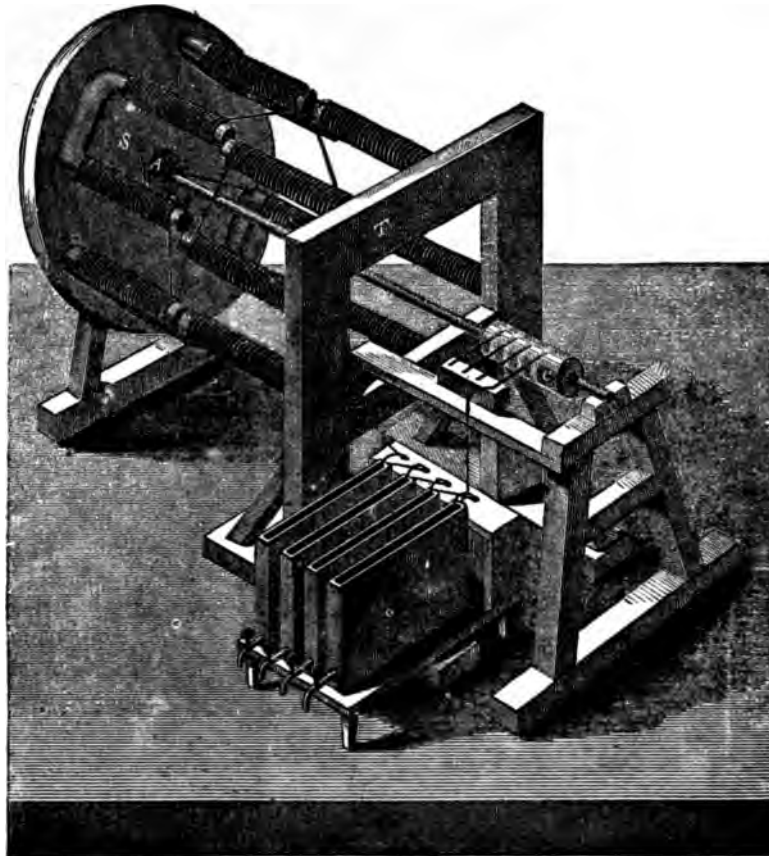


FIG. 4.—JACOBI MOTOR.

the axles of four wheels, and furnished with four sets of iron armatures arranged to pass between the poles of eight electro-magnets. These were placed horizontally at the bottom of the car, two and two, by their opposite poles, in two opposite rows, so that each of the cylinders carried two sets of iron bars parallel to the axles. The bars presented themselves successively, as the cylinders rotated, to the poles of the corresponding opposite electro-magnets. When one of the bars on one side was opposite its magnet, one on the other side was just within range of the attraction of its electro-

side the driving-wheels, were two small cylinders or commutators of ivory and metal upon which bore brushes leading the current from the batteries. Davidson's car was 16 feet long, six feet broad, and of five tons weight, including batteries. He drove it at a speed of four miles an hour with 40 cells composed of plates of iron and amalgamated zinc measuring 15 inches by 12.

An excellent and very early motor was that of Elias, made at Haarlem, Holland, in 1842. It consisted of two concentric rings of soft iron, the inner one being revolvable. The exterior,

fixed ring supported vertically, had six enlargements dividing it into six equal parts. Between the dividing pieces, was wound insulated copper wire, and the winding was such that a current entering at one end of the horizontal diameter was divided between the upper and lower halves of the ring, and left at the other end of the same diameter. The interior ring was of like construction, its six poles being alternately north and south. The current entered by wires with each of which three parts of the commutator were in connection. The motor was worked by two batteries, one for the exterior ring and one for the interior; or by a slight change of connections, one battery only was necessary. In either case, the alternate north and south poles of the exterior ring remained the same. The poles of the inner ring changed polarity at each sixth of a turn, the commutator being so arranged that each pole of the movable ring was always repelled by one of the fixed poles and attracted by the other and next. The windings of the two rings were very close together, so that the action of

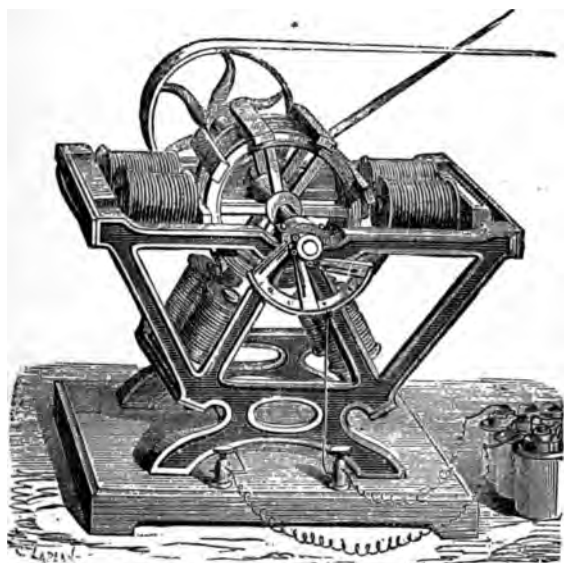


FIG. 5.—FROMENT MOTOR.

parallel currents in them served to assist in the rotation due primarily to the attraction and repulsion of the magnets.

One of the most interesting of the early motors is that of M. Froment, made in 1845 and

illustrated in Fig. 5. It may be likened to a breast-wheel, whose paddles are acted upon by magnetism instead of water. The wheels were made of brass or other non-magnetic material, but the armature bars around the circumference were of soft iron. By means of the commutating device, the current, cut off from each electro-magnet as soon as the armature

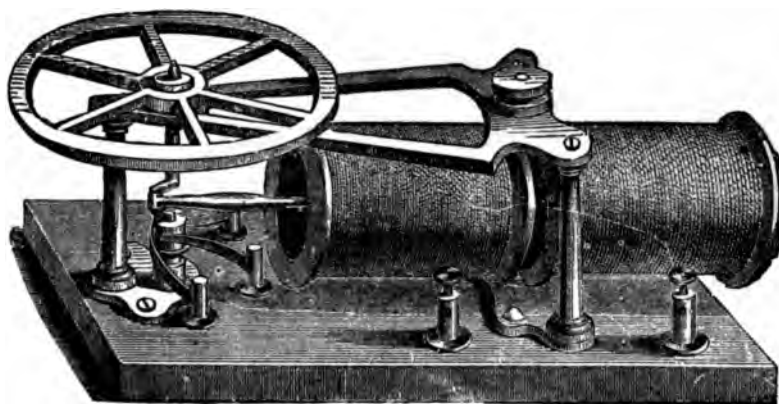


FIG. 6.—DU MONCEL MOTOR.

arrived opposite its poles, was led to another magnet until the said armature had moved on sufficiently to allow the next armature to come within range. The desired effect being obtained, the current was again sent through the first electro-magnet. The commutator consisted of spring rollers in contact with each of the magnets and the battery, and was worked by means of a small cam on the driving shaft. Froment devised other ingenious forms.

In 1851, Count du Moncel devised a motor, Fig. 6, not unlike that of Page, and of which the arrangement reminds one, as he himself said, of an oscillating steam engine. The iron cylinder, which in the position of the crank in the figure, has passed entirely through the right-hand bobbin or solenoid and passed a short distance into the other bobbin, is shown on the point of being attracted into the latter. On arriving at the end of its stroke, it was within reach of an iron ring or disc, terminating the left-hand bobbin. This gave it an extra impetus that carried it over the dead-point corresponding to the movement of the shaft in the opposite direction. Between the bobbins was a roller upon which the iron rod or piston moved, to prevent friction. The commutator was composed of two eccentrics fixed to the axis of the fly-wheel and insulated from each

other. A fixed silver spring in connection with each one of the bobbins encountered at each half revolution of the fly-wheel one of the eccentrics. A third spring large enough to bear upon both of the eccentrics brought the current to the two latter successively.

The Bourbouze motor, also modeled upon that of Professor Page—described in Chapter III.—was made like a steam engine with two pistons. This early type is shown in Fig. 7. At the two extremities of the horizontal beam were two iron cylinders working like pistons inside two long magnetizing bobbins, whose lower ends were occupied by short iron cylinders joined together by a piece of iron between the

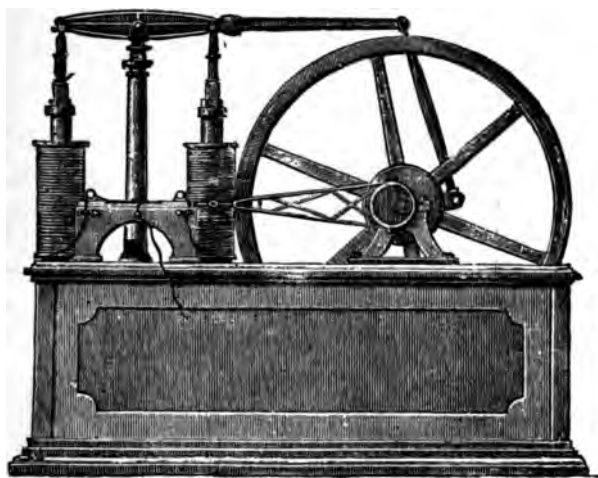


FIG. 7.—BOURBOUZE MOTOR.

bobbins; constituting, in fact, an electro-magnet. When the current passed into one of the bobbins, the corresponding iron rod or cylinder was attracted as well by the magnetic pole at its end as by the coils, and it was drawn downward until the current was cut off by the commutator. The process was repeated in the other bobbin, and the beam was depressed at the corresponding end. This to-and-fro movement was utilized as in steam engines by means of a crank and fly-wheel, in the manner indicated. The commutator was a plate that rubbed alternately on two contacts fixed horizontally on a table, and was set in motion by an eccentric rod worked like that of a steam engine. The Bourbouze motor may be compared to an ordinary working-beam engine.

Last, though not least, but on the contrary of epochal importance, comes the Pacinotti motor

invented by the distinguished Italian physicist in 1861 and described by him in *Il Nuovo Cimento* in 1864. Pacinotti builded better than he knew, and it was not until 1871 when the celebrated Gramme dynamo with ring armature made its appearance, that he recognized the true value of his motor and brought it from its obscurity and oblivion in the Philosophical Museum of the University of Pisa to be seen at the exhibitions of Vienna in 1873, and of Paris in 1881. Under the title: "A description of a Small Electro-Magnetic Machine," Dr. Pacinotti said: "I took a turned iron ring furnished with sixteen equal teeth. This ring was suspended by four brass arms *B B* (Fig. 8), which fixed it to the axis of the machine. Between these teeth little triangular pieces of wood were let in, wound with silk-covered copper wire. This arrangement was to obtain perfect insulation of the coils or bobbins thus formed between the iron teeth. In all the bobbins the wire was wound in the same direction, and each was formed of nine turns. Each is thus separated from the other by an iron tooth and the triangular piece of wood. On leaving one bobbin to commence the next, I end the wire by fixing it to the piece of wood which separates the two bobbins. On the axle carrying the wheel thus constructed I grouped all the wires, of which one end formed the end of one bobbin and the other the commencement of the next, passing them through holes for this purpose in a wooden collar fixed on this same axle and then attaching them to a commutator also on the axle.

"This commutator consisted of a ring or small cylinder of wood, having on its circumference two rows of grooves, in which are fitted sixteen pieces of brass (eight in each row); they are placed alternately, and concentric with the wooden cylinder on which they form a spindle. Each of these pieces of brass is soldered to the two ends of wire corresponding with two consecutive bobbins; so that all the bobbins are connected, each being joined to the following by a conductor, of which one of the pieces of brass of the commutator forms a part. If we put two of these pieces of brass in communication with the poles of a battery by means of two metallic rollers, *G*, the current, in dividing, will go through the coil at both points where the ends of the wire fastened to the pieces of brass communicate with the rollers; and magnetic poles

will appear in the iron circle in the diameter perpendicular to *AA*. On these poles acts a fixed electro-magnet, which determines the rotation of the circular electro-magnet; the poles of the circular electro-magnet when in movement always appearing in the fixed positions corresponding to the communication with the battery."

He said further:—"It seems to me that what increases the value of this model is its faculty for being transformed from electro-magnetic into magneto-electric with continuous current.

permanent magnet; the electro-magnetic machine resulting from this will have the advantage of giving additional induced currents all in the same direction, without necessitating the use of mechanism to separate the opposite currents or make them converge." As to reversibility, he remarked with keen foresight:—"This model further shows how the electro-magnetic machine is the complement of the magneto-electric machine, for, in the first, the current obtained from any source of electricity circulating

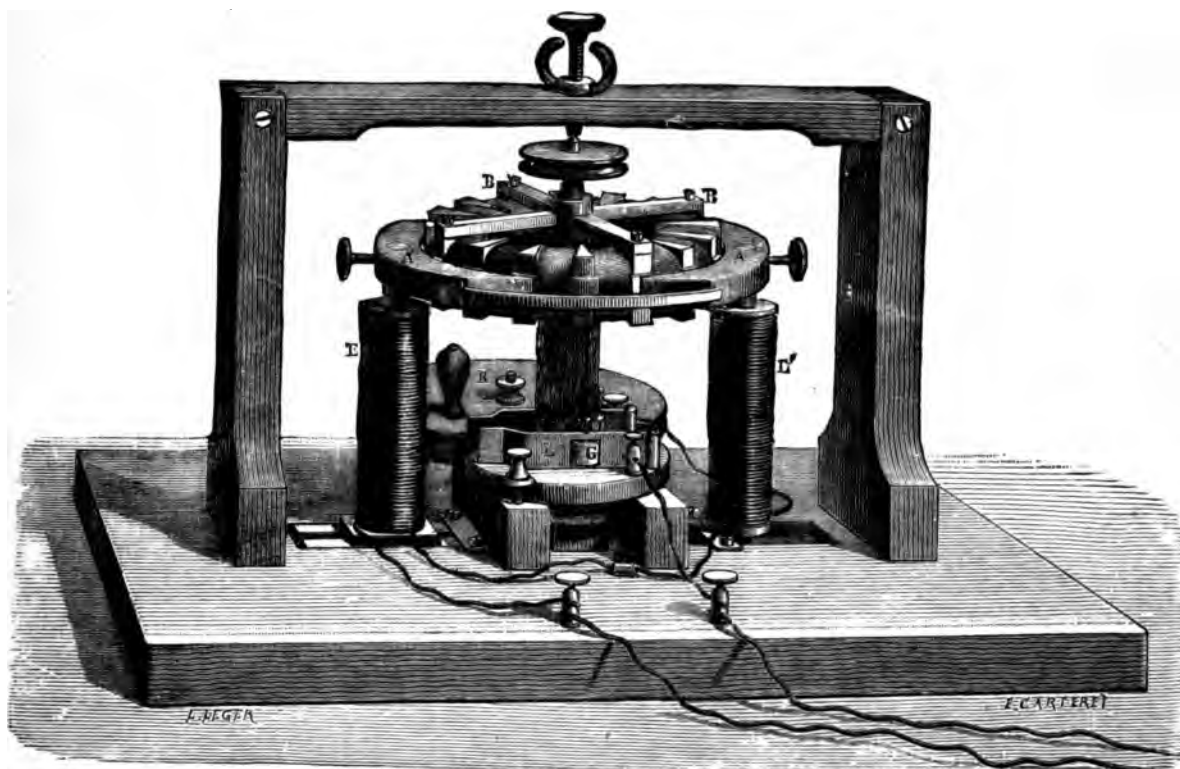


FIG. 8.—THE PACINOTTI MACHINE.

If, instead of the electro-magnet, there was a permanent magnet, and the circular magnet was made to turn, we should have, in fact, a magneto-electric machine which would give a continuous induced current always in the same direction. To develop an induced current by the machine thus constructed, I brought to the magnetic wheel the opposite poles of two permanent magnets, or I magnetized by means of a current the fixed electro-magnet, and I made the circular electro-magnet to turn on its axis. In both cases I obtained an induced current always in the same direction. It will easily be seen that the second method is not practicable, but that an electro-magnet is easily replaced by a

in the bobbins produces movement of the wheel with its consequent mechanical work; whilst in the second, mechanical work is employed to turn the wheel, and obtain, by the action of the permanent magnet, a current which may be transmitted by conductors to any required point."

Other early European experimenters of merit might be mentioned, such as Wheatstone, McGawley, Gaiffe, Larmenjeat, Roux, and Hjorth, but the descriptions above will serve to show the state of the art as regards electric motors down to the time when the reversibility of the dynamo-electric machine gave an entirely new direction to the efforts of inventive genius in Europe.

CHAPTER III.

EARLY MOTORS AND EXPERIMENTS IN AMERICA.

As all previous works dealing in any way with electric motors have little to say about American work in the field, no apology need be offered for the effort made in this chapter to supply, in part, the deficiency.

The first electric motor patented in this country was constructed early in 1837, and was the device of Thomas Davenport, a blacksmith, of Brandon, Vt., who styled his invention an "Application of Magnetism and Electro-Magnetism to Propelling Machinery." The frame of the machine was made of a circular ring and disc, horizontally arranged, the former being supported upon the latter by vertical posts. Upon the lower disc were mounted two copper

magnets, and being semi-circular in shape, they approximated the form of a horseshoe. The principle of operation of this machine will be apparent at a glance. The polarity of the electro-magnets was changed during their revolution by the wiping contact of their connections with the two segmental plates on the bottom disc, these segments connecting with the positive and negative poles of the battery.

As a remarkable instance of the granting of a broad claim by the Patent Office to an inventor, that of Davenport may be cited. It reads:—"Applying magnetic and electro-magnetic power as a moving principle for machinery in the manner above described, or in any other substantially the same principle."

To Davenport appears to belong the honor of first printing by electricity as well as of first building an electric railway. A paper called *The Electro-Magnet and Mechanics' Intelligencer* was published by him in 1840. It is said that he obtained the current for his machine from a battery of amalgamated zinc and sheets of platinized silver. Pieces of sheet iron platinized might, he thought, be used with advantage instead of the silver plates. The electrodes were plunged into water acidulated with sulphuric acid in the proportion of nine parts of water to one of acid. Davenport and Ransom Cook are said by Prof. Moses G. Farmer to have used in 1840, with motors, a zinc and copper battery, with a solution of blue vitriol as the exciting fluid.

Davenport was a man far ahead of his time. Having seen a magnet in use at Crown Point, on Lake Champlain, in 1833, extracting iron from pulverized ore, he jumped at once to the idea that he could apply magnetism to the propulsion of machinery. He bought the magnet, began to experiment, and by 1834 had obtained rotary motion. He then went to Washington, where he took steps to obtain the patent above mentioned, and in the autumn of 1835 he set up a small circular railway at Springfield, Mass.,

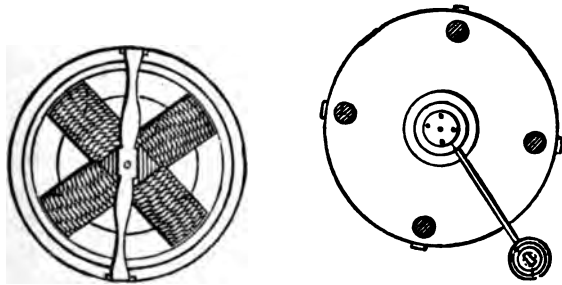


FIG. 9.—DAVENPORT MOTOR.

segments, arranged in the centre, as seen in the sectional view, which, together, constituted a circular ring pole-changer. The electro-magnets were four in number and projected horizontally in radial lines from a common centre, Fig. 9. Through this centre passed a vertical shaft having bearings in the frames so as to have a revolving motion. The conducting wires from the source of energy extended up from the copper segments parallel with the shaft of the electro-magnet. Davenport arranged within the inner periphery of the upper horizontal ring a ring of steel cut in two, forming a pair of steel segments, which he termed "artificial magnets." The description of this device in the patent specification is somewhat obscure, but the inference is that these were permanent

over which he ran an electro-magnetic engine. In December of the same year he exhibited his road in Boston for two weeks. During 1837 he showed to Prof. Benjamin Silliman, in New York, a motor in which "the exterior fixed circle is now composed entirely of electro-magnets. The conducting wires were so arranged that the same current that charged the magnets of the motive wheel charged the stationary ones placed around it, only one battery being used. It lifted sixteen pounds very rapidly, and when the weight was removed, it performed more than six hundred revolutions per minute."

In June, 1838, Nelson Walkly, of Tuscaloosa, Ala., devised an electric motor, the principal improvement being in the mode of changing the poles of the electro-magnets.

The electro-magnets employed by Walkly were semi-circular in form. Two of them were fixed to a horizontally-revolving wheel with proper insulations. The ends of the wires from the revolving magnets were connected with two segmental collars placed on the vertical shaft. These collars were placed, one above the other, on the shaft, but insulated therefrom. The currents of the two revolving magnets were taken off by wiping electrodes arranged to lie against the collars which led to the negative and positive elements of the battery; Fig. 10.

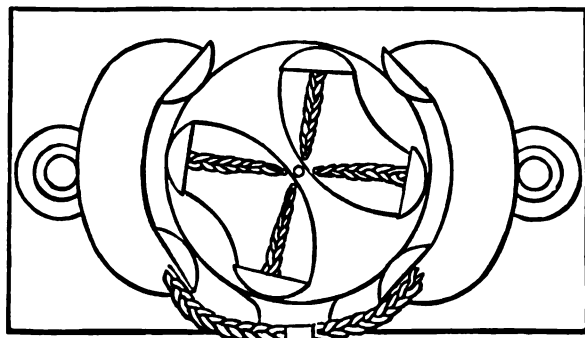


FIG. 10.—WALKLY MOTOR.

Through a post fixed in the right-hand side of the upper platform, Fig. 11, were fixed two conductors connected with the battery. The outer ends of these spring conductors, when at rest, pressed against an insulated pin, and between their ends was interposed a lever, the end of which was just the size of the insulated pin. This lever was composed of two plates of metal with a piece of wood between them, and

was made to vibrate by means of a double elliptic cam fixed on the upper end of the vertical shaft by means of a connecting pitman. Should more revolving magnets be used than two, the cam might be fixed on a pinion, revolving more times than the main shaft, so as

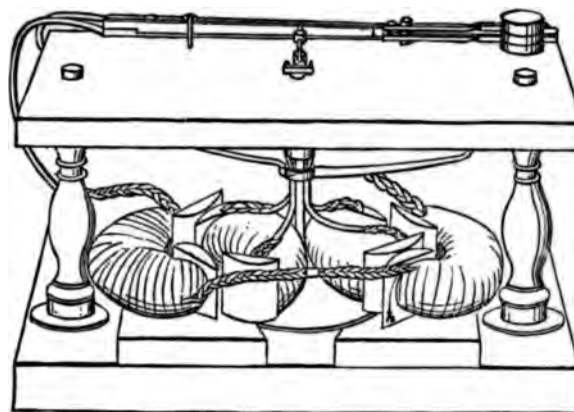


FIG. 11.—WALKLY MOTOR.

to change the polarity every time one of the rotary magnets came opposite one of the stationary ones.

To magnetize the outer, or stationary, magnets, the current of electricity passed from the positive side of the battery to the conductor, and thence to the lower plate of the vibrating lever, and so to one of the stationary magnets. When the machine was at rest, the lever would be in contact with the spring conductors, and the ends of the rotary magnets opposite the ends of the stationary ones. By moving the rotary magnets the cam would move the end of the lever and the end of the spring away from the insulated pin, leaving the opposite spring resting against the pin. The north poles of the stationary and rotary magnets would then repel each other, causing the latter to revolve, so that the lever was vibrated back, thereby moving the spring on the opposite side and changing the polarity of the stationary magnets, and so on.

The next American patent for an electrical motor, in chronological order, appears to be that granted to Solomon Stimpson, September 12, 1838, Figs. 12 and 13. Between two vertical circular brass rings were attached the poles of a series of stationary magnets by screws. Within or between the stationary magnets were a series of revolving ones mounted upon a

central shaft, the whole number of magnets—both stationary and revolving—being twelve. The wires of all the stationary electro-magnets were connected terminally with mercury-holding cells resting on the base plate. These insu-

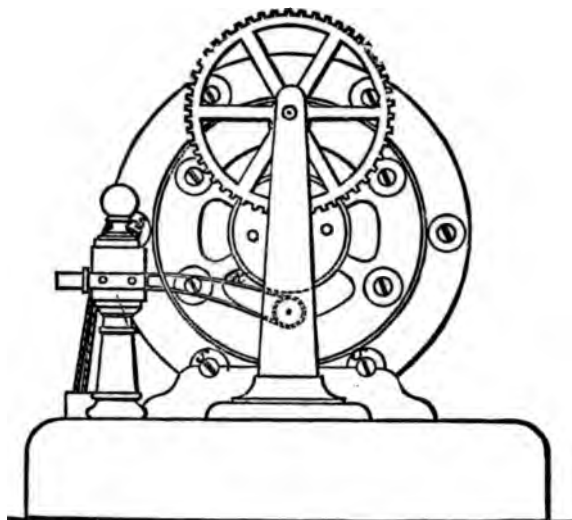


FIG. 12.—STIMPSON MOTOR.

lated cells, the inventor explained, were for battery communications. The electric connections of the revolving magnets passed out at one side and were connected with a pole-changer.

The galvanic current was not distributed to the revolving magnets individually, but they were charged by pairs, the magnets of each

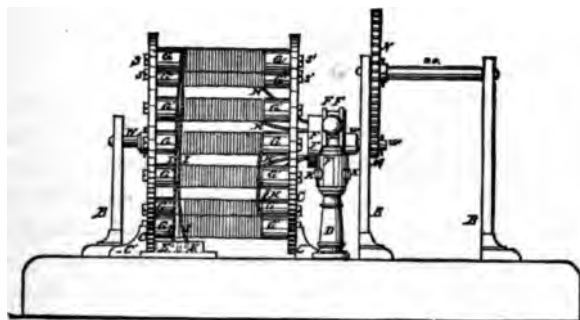


FIG. 13.—STIMPSON MOTOR.

being charged in sequence. Wiping springs connected with the conducting wires were arranged to lie against the revolving pole-changer, which was composed of a series of metallic segments with interposing insulating material. The wiping contact was made upon the opposite sides of the pole-changer, and thus

were constituted two permanent battery poles. As the machine revolved, the two opposite extremities of the wires were presented in alternate order to the same battery pole, and thus a change of polarity was effected. Power was applied through a pinion on the shaft commencing with the cog gear.

The patent of Truman Cook, of New York, was granted in 1840. The body of the rotating armature, Fig. 14, was made of wood, brass, or any other material not affected by magnetic influence. Upon the periphery of this armature were placed six rectangular bars of soft iron, at equal distances apart, and extending from end to end parallel with the axis. The electro-magnets were of the usual horseshoe

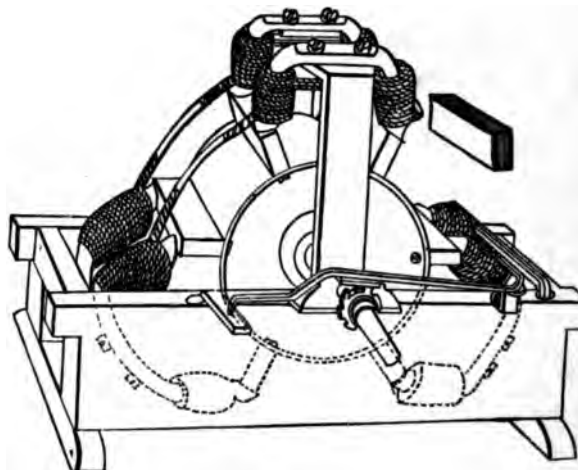


FIG. 14.—COOK MOTOR.

form, and were placed in pairs, so that the opposite poles of each of them, at the same instant, stood immediately over the ends of the two contiguous armatures or keepers. In this machine there were three pairs of electro-magnets.

There were two mercury cups located in the frame in which the ends of the electro-magnet coils terminated, those wires which formed one termination passing into one cup, and those forming the opposite electric pole passing into the other mercury cup. A cam wheel secured to the armature shaft was made to touch the terminal wires from one electric pole, so that the ends of the wire were lifted from the mercury cup at each rotation.

The notches shown in this cam wheel corresponded with the number of the revolving armatures, and were so arranged as to sus-

pend the transmission of the current, and, consequently, the magnetic induction at the proper moment for allowing the armatures to pass the magnets. One of the projecting teeth on the cam was insulated, and it was this one that raised the terminal wires of one electric pole by the action of the cam. In the drawings these wires are not represented as dipping into the mercury cup, but as resting upon a piece of metal which forms a conducting communication with the cup.

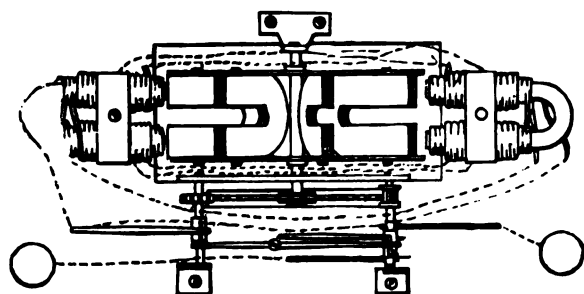


FIG. 15.—LILLIE MOTOR.

The length of the several armatures was less than that of their distance from each other, and the north and south poles of the magnets, constituting each pair, were at a distance apart corresponding to the distance of the armatures. The influence of the magnetic field was consequently exerted between the opposite poles of the magnets constituting the pair, this resulting from their proximity being greater than that of the opposite poles of each individual magnet.

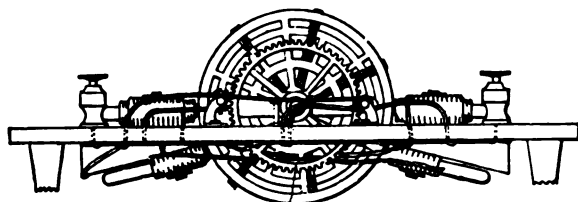


FIG. 16.—LILLIE MOTOR.

It will be perceived that these magnets operated in pairs, one of them extending its influence directly to the other, thus mutually actuating the armatures as they approached. Mr. Cook showed a modified form of armature in the detail view, which consisted of several plates of soft sheet iron, placed side by side, with narrow sheets of copper interposed between them at each end.

In 1850, John H. Lillie, of Joliet, Ill., constructed an electric motor comprising a series

of radially arranged permanent horseshoe magnets, revolving on a wheel in proximity to stationary electro-magnets, Figs. 15 and 16. A helix of fine wire was wound around the outside of the electro-magnet, "for the double purpose," he said, "of producing other electro-magnets, and to destroy the secondary or vibratory currents in my first electro-magnet."

On one end of the axis of the wheel to which the permanent magnets were attached was a large spur-wheel, which drove two pinions to which the commutator was attached. The frame of the machine received two stationary electro-magnets on a line radial from the shaft, one on each side. Around the usual coils of the electro-magnets were wound secondary coils which were connected with the electro-

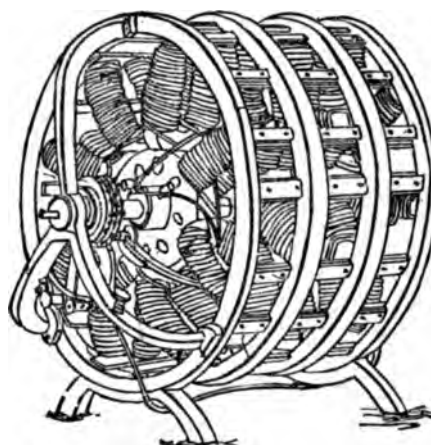


FIG. 17.—NEFF MOTOR.

magnets placed below the bed-plate of the frame, where they formed a circuit and caused the latter magnets to be energized. Secondary currents were said to be destroyed in this way. The lower magnets were so placed as to aid in the propulsion of the wheel. Mr. Lillie found it necessary to have the permanent magnets quite long, otherwise their poles would be changed by a powerful current in the electro-magnet.

Jacob Neff, of Philadelphia, devised an electric motor in 1851, Figs. 17 and 18. The metal frame of the Neff electric motor was connected by cross-bars, to which the armatures were attached in such a manner that each magnet had a separate armature. The rotating wheel of electro-magnets was secured by means of insulated nuts in the wheel-frame, which was tapped for the purpose of receiving the magnets.

The commutator was composed of three separate discs. The outside ones had flanges, by means of which they were secured to the shaft, and they were also adjusted, as circumstances might require, by means of set screws, non-conducting substances being placed between the discs. Each disc had sixteen platinum points on its periphery, corresponding in number to the armatures. Friction rollers covered with platinum were arranged to work under the commutators, they being retained in their position by set screws above their journals and spiral springs beneath. The commutators completed the circuit when the battery was connected, and the magnets were energized as they came in contact with the friction rollers and demag-

netized as they left it. On each side of these collars of brass, at a sufficient distance apart, were arranged on the axis a series of arms between each two of which the legs of the magnet were allowed to pass, and on which they exercised their attractive force alternately as the

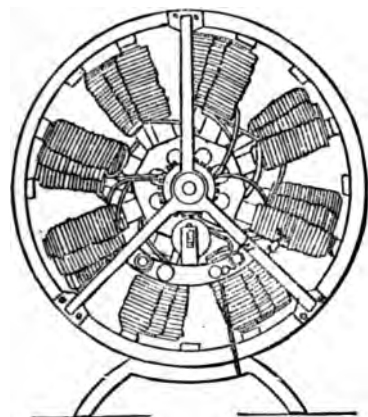


FIG. 18.—NEFF MOTOR.

netized as they left it. As will be understood, the magnets were energized when their edge was near the edge of the armatures, and continued attracting until the magnets were immediately under or opposite to the armatures. The connection was then broken and the magnets passed freely under the armatures.

Another interesting early motor patented about this time was that of Thomas C. Avery, of New York, Figs. 19 and 20. In this electromagnetic engine, Avery combined a series of electro-magnets in pairs so as to present their poles toward a common centre, sufficient space being provided between the poles of the magnets for an intervening axis. This axis consisted of revolving sets of bars extending radially outward and passing between the poles of the magnets. At the points where the ends of the magnets approached the axis, pieces of brass or other non-magnetic material were interposed to prevent the ends of the magnets

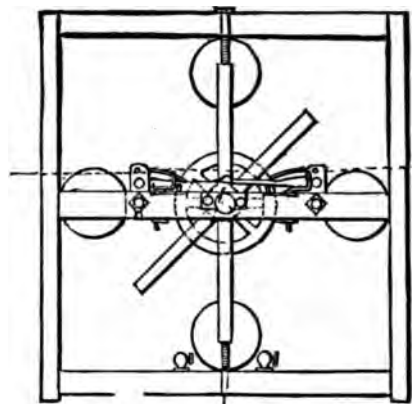


FIG. 19.—AVERY MOTOR.

circuit was made and broken through the opposite pairs of electro-magnets. Two cams were attached to the rotating axis for the purpose of breaking and changing the direction of the electric current from the vertical to the horizontal magnets continuously. Two circuit closers acted at their outer ends on these cams by means of compression springs, and were

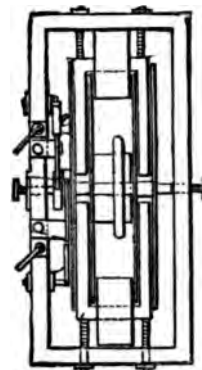


FIG. 20.—AVERY MOTOR.

attached at their back ends by a screw to support pieces fixed to the side of the frame. These support pieces were attached to a cross-bar, and were in contact with conducting material secured to the under side of the cross-bar for the purpose of reversing the direction of the electric currents.

In 1852, John S. Gustin, of Trenton, N. J., constructed an electric motor arranged for operating a pump. A side and an end elevation, Figs. 21 and 22, are here given. In connection with the oscillating beam shown was a pendulum arm extending downward and carry-

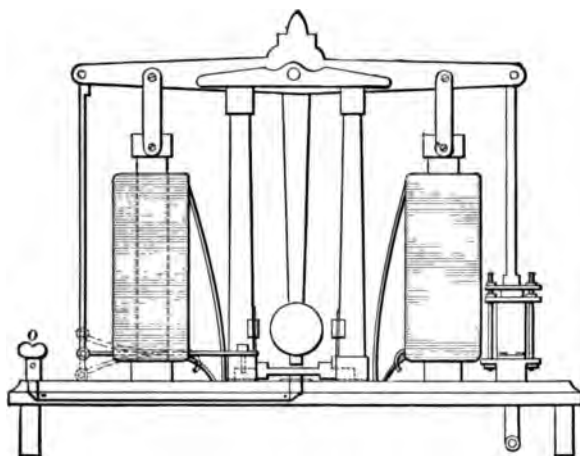


FIG. 21.—GUSTIN MOTOR.

ing a weighted ball. At the lower extremity of this pendulum was a projection which moved the valve, alternating the battery current on the magnets by the vibrating motion of the pendulum. The pendulum was intended to move between two spring-buffers at either end of its throw, which were designed to relieve the force of the blow of the pendulum, and also to assist in reversing its motion. On the valve or break-piece was a conducting plate, its length so adjusted that it could form a connection with but one side at the same time. The negative wires from the helices were both led to a like strip of copper on the opposite side of the bed-plate. At either end of the oscillating beam were pivoted links which connected or suspended the armatures of the magnets. The arrangement of the pump is shown at one side of the device, its piston-rod being connected with one end of the working-beam. At the opposite end of the beam was a long depending link which was pivoted at its lower end to a regulating spring. One end of this spring was securely fixed in the frame.

A thin piece of rubber cloth was placed on the magnet poles to prevent the adhesion of the armature to the magnets when the battery current was broken, and also to prevent violent concussion of contact. The regulating

spring was adjusted in its tension in this machine so as to require twenty pounds force to move it one inch to the point of extension (shown by dotted lines) with the rod from the working-beam, and so set as to be at rest when the pendulum was central. The object of the regulating spring was to receive the excess of power of the electro-magnets when they were closing and to give it off when they were too far extended for the attractive force to be available. With the assistance of the pendulum and this spring, nearly an equal force was said to be exerted throughout the stroke of the pump. Gustin stated that the tension of this regulating spring should be fully equal to the power required to move the pump when the spring was at its extreme point of action. At that point the electro-magnets of the Gustin motor were so feeble that the spring had nearly the whole work to perform.

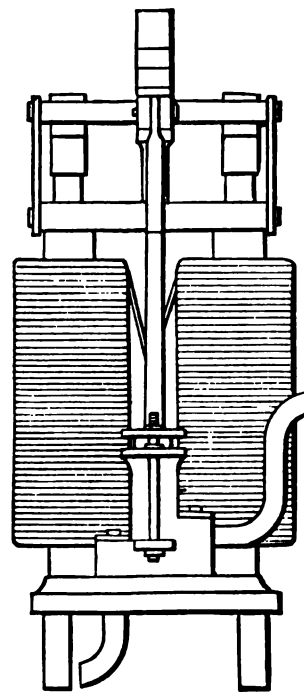


FIG. 22.—GUSTIN MOTOR.

In the same year Gustin devised another electro-magnetic motor. The legs of the magnets of this motor were nine inches long and cylindrical; the armatures were of the same length and form, and were adapted to move longitudinally in the helices which projected beyond the poles of the magnet forming a hollow core. Five magnets were employed and

ten armatures, there being an armature to each pole of the magnets. Adjusting nuts were employed to secure the armatures in different relative positions on their supporting rods.

The armatures of one magnet of the series were arranged to allow of a play of one inch, the armatures of the next magnet having a play of two inches, and so on. At the energization of the series, the magnet whose armatures had the play of one inch was the most powerfully attracted, whereupon the current was broken on that magnet and closed upon the next magnet of the series. A like result was produced successively upon all the magnets of the series until they had all performed their work. The stroke of the working-beam was not yet complete, however, when the fifth pair of magnets closed. One series of magnets

a piston-rod connected to the crank of a shaft carrying a fly-wheel. The core moved downward by its weight until its upper end was just leaving the solenoid, and thus one movement of the piston was accomplished. On passing the current the core or piston was attracted upward, and thus the second movement was completed. A commutating device was attached to the shaft which automatically admitted the current into the coil and cut it off at the right moment.

Professor Page soon improved on this single-acting electric engine by adding another solenoid, which could pull the piston in the other direction without the assistance of gravity. Fig. 23 shows this form of engine which takes electricity at both ends of the "cylinder," to borrow the expression of steam engineers. This

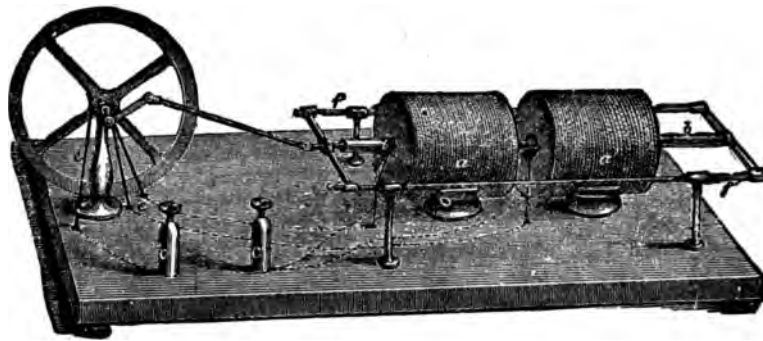


FIG. 23.—PAGE MOTOR.

having performed their work, the other series, working in connection with the opposite end of the working-beam, were in readiness to perform their work in like manner. The motion of the working-beams was communicated through their bearing-rods to the crank and fly-wheel, thereby producing rotary motion.

The most celebrated early motor next to that of Jacobi was undoubtedly that of Prof. C. G. Page, of the Smithsonian Institute. This depended upon a different principle from that of the others. When the end of a bar of iron was held near a hollow electro-magnetic coil or solenoid, the iron bar was attracted into the coil by a kind of a sucking action until the bar had passed half way through the coil, after which no further motion took place. Professor Page constructed an electric engine on this principle about 1850. The solenoid was placed vertically, like the cylinder of an upright engine. A rod of iron, by way of armature, was fastened to

arrangement will be readily understood. There are two solenoids and each has its iron rod passing through it, though they are joined into one piston by a piece of non-magnetic material. The piston is attached to a frame *f f'* which slides through supports, and in this way it is free to move inside the solenoids. The current is sent alternately through each coil by an eccentric disc on the axle (which suggests a further resemblance of this motor to a steam-engine). This eccentric touches first one and then the other of two springs *e e*, connected to the solenoids.

A large motor of this description was constructed by Professor Page, in 1850, which developed over ten horse-power. Professor Page sought to apply his motor to locomotion, and he actually constructed an electric locomotive to demonstrate the practicality of his scheme. But he never achieved much success, as might have been foreseen. Among the improvements

which Professor Page introduced was that of making each solenoid double, so that the arms of a U magnet could slip into them, instead of one single bar. As the solenoids attracted most strongly when the cores were almost out of them, he wound his solenoids in short sections, and a sliding commutator worked by the motion of the cores successively cut out the sections of coil which the cores had entered and transferred the current to others ahead of them, and thus the range of attraction was greatly increased.

Professor Page, it is interesting now to recall, made the trial trip with his electro-magnetic locomotive on Tuesday, April 29, 1851, starting from Washington, along the track of the Washington & Baltimore Railroad. His locomotive was of sixteen horse-power, employing 100 cells of Grove nitric acid battery, each having platinum plates eleven inches square. The progress of the locomotive was at first so slow that a boy was enabled to keep pace with it for several hundred feet. But the speed was soon increased, and Bladensburg, a distance of about five miles and a quarter, was reached, it is said, in thirty-nine minutes. When within two miles of that place, the locomotive began to run, on nearly a level plane, at the rate of nineteen miles an hour, or seven miles faster than the greatest speed theretofore attained. This velocity was continued for a mile, when one of the cells cracked entirely open, which caused the acids to intermix, and, as a consequence, the propelling power was partially weakened. Two of the other cells subsequently met with a similar disaster. The professor proceeded cautiously, fearing obstructions on the way, such as the coming of cars in the opposite direction, and cattle on the road. Seven halts were made, occupying in all forty minutes. But, notwithstanding these hindrances and delays, the trip to and from Bladensburg was accomplished in one minute less than two hours. The cells were made of light earthenware, for the purpose of experiment merely, without reference to durability. This part of the apparatus could therefore easily be guarded against mishap. The great point established was that a locomotive, on the principle of Professor Page, could be made to travel nineteen miles an hour. But it was found on subsequent trials that the least jolt, such as that caused by the end of a rail a little above the level, threw the batteries out of work-

ing order, and the result was a halt. This defect could not be overcome, and Professor Page reluctantly abandoned his experiments in this special direction.

It is interesting here to note that in 1847, the versatile and unwearied investigator, Professor Moses G. Farmer, constructed and exhibited in public an electro-magnetic locomotive, drawing a little car that carried two passengers on a track a foot and a half wide. He used forty-eight pint cup cells of Grove nitric acid battery. In 1851, Mr. Thomas Hall, of Boston, then at work for Mr. Daniel Davis, constructed and exhibited at the Charitable Mechanics Fair in Boston, the little locomotive, Fig. 24.

Our illustration is taken direct from the original woodcut of the locomotive. The block was made nearly thirty-seven years ago, and first appeared in Palmer & Hall's catalogue of 1850. The engine which it represented was on

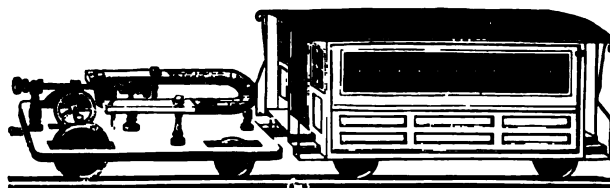


FIG. 24.—HALL LOCOMOTIVE OF 1850-1.

the principle of an electro-magnet revolving between the poles of a permanent magnet. The armature had a worm on its shaft which matched into a gear attached to the driving wheels, the latter being insulated by ivory. The track was laid in five-foot sections, and was about forty feet long and five inches wide. Under the platform of the car was a pole-changer attached to a lever; when the engine reached the end of the track it ran against an inclined plane which reversed the pole-changer and sent the engine to the other end of the track, where the same thing was repeated: thus the engine was sent automatically from one end to the other. The current, produced by two Grove cells, was, it is well to note, conveyed to the engine by the rails. We have seen, also, a photograph of the "Volta," a finely-constructed model, which was made on the same principle as the above, but so as to resemble very closely a locomotive actuated by steam. Mr. Hall says that in 1852 he made, for Dr. A. L. Henderson, of Buffalo, a model

line of railroad with electric engine, with depots, telegraph line, and electric railroad signals, together with a figure operating the signals at each end of the line automatically. This, he states, was the first model of railroad signals or trains worked by telegraph signals.

Professor Page, in 1854, patented a modification of his early ideas. Figs. 25 and 26. This later motor resembled in external appearance, to

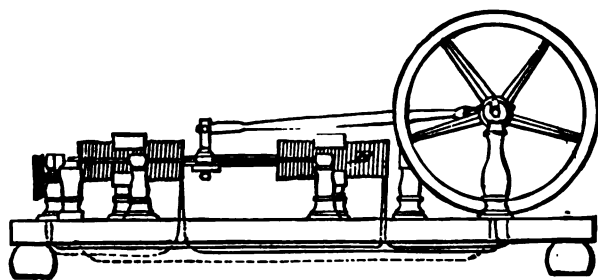


FIG. 25.—PAGE MOTOR.

some extent, a double-action, slide-valve steam pump. This Page motor comprised two parallel axial bars working through two pairs of helices, and two fixed armatures arranged at either extremity of the parallel bars. The pitman-rod connected the crank of the fly-wheel to the cross-head of the axial bars. The two pairs of helices were each connected by wires with the two conducting springs shown in the detail view, each bearing alternately against the cut-off on the fly-wheel shaft. This connection was made by means of the wires passing down under the base-board and up through

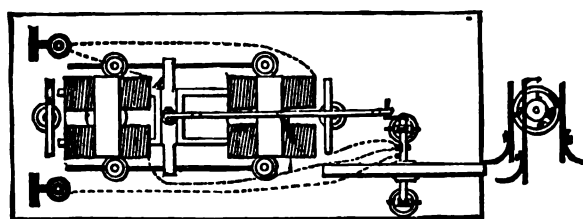


FIG. 26.—PAGE MOTOR.

to their respective connections, as shown by the dotted lines. This fly-wheel cut-off or commutator consisted of two semi-cylindrical metallic segments insulated from each other and secured to a cylinder of wood upon the shaft. An entire metallic ring was fixed upon a part of the wooden cylinder of less diameter than that to which the insulated segments were attached. This ring was connected by a strip

of metal with one of the metallic segments. The three conducting springs are shown in position in the detail view.

The spring in contact with the smaller ring connected with the positive pole of the source of electrical energy, and the current, therefore, passed through the metallic connections to the spring at the left-hand side of the detail figure. This latter spring was connected with one termination of the helices to the left of the drawing, the other being connected with the negative pole. The commutator revolved in the direction of the arrow. The axial bars are shown with thin poles passed entirely through the helices and within the influence of the armature. The instant the dead point was reached, the other pair of helices was charged to propel the frame of axial bars in the opposite direction. This was effected by the revo-

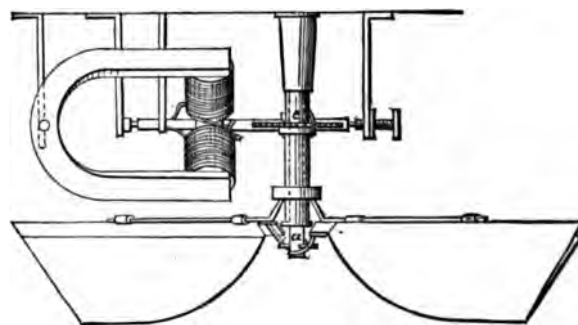


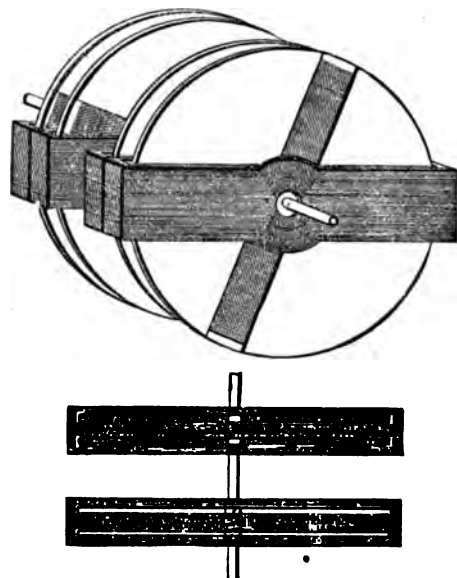
FIG. 27.—STEIN MOTOR WITH FAN.

lution of the commutator in the direction of the arrow, the metallic segments being reversed. The very short distance through which the magnets acted with power, and the rapid diminution of power as the magnets receded from each other, presented serious practical difficulties in this as in other electro-magnetic engines, whether in the reciprocating or rotary form. Dr. Page asserted that by the employment of a reciprocating core arranged to move in the line of its length through an arrangement of helices, the magnetic power could be made to act with more uniformity through a considerable distance, as some portion of the magnetic core would be always in close proximity to the helix.

In the latter part of 1854, Louis Stein devised an electric motor for operating a revolving fan, Fig. 27. The device was intended to be attached to the ceiling in the manner now familiar. The main pendent vertical shaft carried the wings of the fan. This shaft had a

worm-wheel keyed to it, and to the armature shaft of the electric motor was affixed a worm which meshed with the worm-wheel and revolved the fan. The electro-magnets were arranged at equal distances apart around the horizontal shaft. Armatures were arranged at suitable distances around the series of electro-magnets, so that when the battery was in action the shaft was kept in motion and the fan revolved. This patent of Stein was more on an application of the electric motor than an improvement in the motor itself.

The electric motor of Maurice Vergnes, Figs. 28, 29 and 30, comprised four wheels or discs composed of wood and revolving upon a common axle. Each disc included an electro-magnet arranged thereon diametrically on both sides of the disc, so that the magnets were parallel. Each pair of the magnets communicated with a separate battery and revolved in a peculiarly arranged "multiplying coil," the coils being side by side and parallel to each other. There were two of these multiplying



FIGS. 28 AND 29.—VERGNES MOTOR.

coils, which communicated with separate batteries, which, together with the separate batteries requisite for the electro-magnets, made in all four distinct batteries of equal intensity. By means of pole-changers the direction of the electric current was reversed in the multiplying coils at every half revolution of the wheels, and in each pair at the moment when the other

pair was exerting its greatest force. The conducting power of the multiplying coil was said to be equal to the conducting power of the electro-magnet revolving therein.

By referring to the drawings it will be seen that the magnets were straight bar magnets

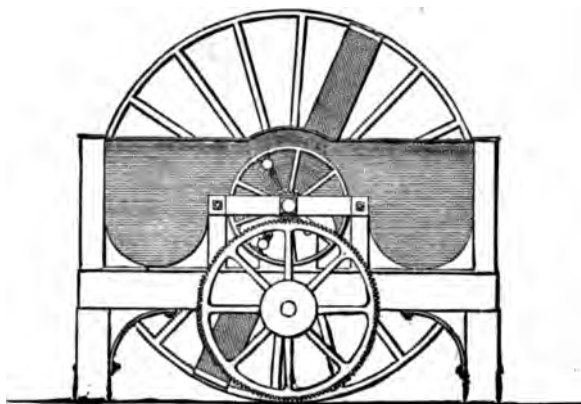


FIG. 30.—VERGNES MOTOR.

and that the multiplying coils or helices formed an inclosing horizontal band through which the discs and their magnets revolved. The currents in the two multiplying coils were reversed alternately so as to produce a continuous revolution of the electro-magnets without any change in their polarity. The commutator was arranged on the shaft between the two pairs of rotating, magnet-carrying discs.

Maurice Vergnes in 1860 again appeared in the field of electricity, with an improvement upon the electric motor just described.

Instead of employing two distinct sets of electro-magnets revolving in double stationary helices, he now used a single wheel, the spokes of which were electro-magnets turning within a single set of helices. The distinguishing feature of the later construction was the disposition of the series of electro-magnets on a common axle and revolving within stationary helices, so that all the electro-magnets had, when passing through one end of the helices, a like polarity, and *vice versa*. Vergnes asserted that by this arrangement he obtained a continuous rotary motion without any dead point, and could develop considerable power. His second device is illustrated in Fig. 31. The two rectangularly arranged helices, within which the magnet-carrying wheel revolved, were supported in a horizontal position upon a table or frame, as shown in the figure. The magnetic

wheel revolved within these helices, the axle of which passed between them. The wheel itself was composed of two flat electro-magnets placed at right angles with each other, and on a common centre on the shaft. The disposition of the elements of this apparatus was such that when one electro-magnet approached an inclination of forty-five degrees with the helices in

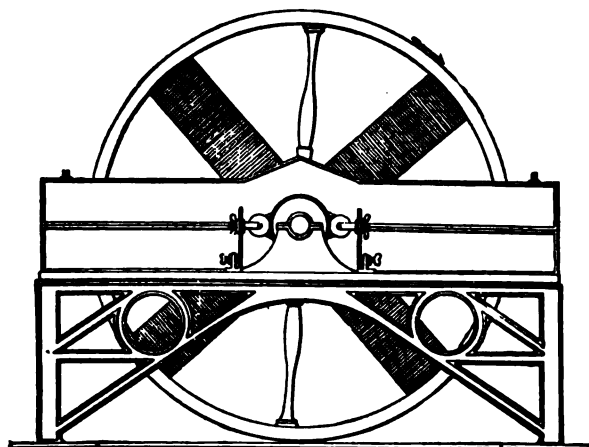


FIG. 31.—MODIFIED VERGNES MOTOR.

its rotation, the current passed into the magnet. The other bar magnet was energized in the same manner. The commutator was provided with anti-frictional contact electrodes.

The patent of Yeiser, granted in 1858, employed what was at that date a novel mechanical arrangement for obtaining the full measure of the attractive power of an electro-magnet upon its armature. The operation of this device will be readily apparent from an inspection of Fig. 32. A series of balance beams arranged one above the other was employed. To both ends of these beams were attached armatures of equal weight, which came into the magnetic field successively and were attracted to the magnets so that each one in turn became momentarily in effect an elongation and a part of the electro-magnet. At each end of the machine was arranged a series of upright electro-magnets side by side, so that all their poles were in the same horizontal plane. The circuits of the two series of magnets, were, however, independent of each other. The length of the series of armatures was sufficient to cover the poles of all the magnets at each end.

The commutator for closing the circuits alternately through the two series of magnets was mounted upon the driving shaft above the

armature beams. The commutator consisted of a wheel, one-half of the periphery of which was insulated in the usual way. The circuit was changed from one to the other of the series of magnets twice in every revolution of the shaft.

The distance between the horizontally arranged armature beams was such that the beams had a limited amount of movement independent of each other, the lower beam being pivoted so that it could have no more vibratory movement than that of the several beams pivoted above it.

In the electric motor patented to Lewis H. McCullough, February 26, 1867, a vertically arranged vibratory armature-carrying beam was the main feature. Fig. 33 is an illustration of the McCullough motor. Two pairs of electro-magnets, one above the other, were arranged on both sides of the vertical oscillating beam, and so that the double armatures lay in the same horizontal plane as the magnets.

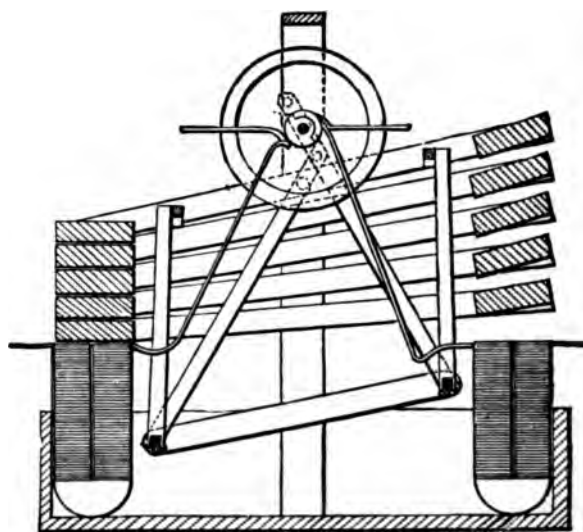


FIG. 32.—YEISER MOTOR.

Each pair of armature plates was equidistant from the pivotal point of the axis of the vibrating beam. Attached to the upper end of the beam by means of a wrist-pin was a pitman through which rotary motion was communicated. An endwise disposition of the magnets for the purpose of increasing or diminishing their attractive force was accomplished by adjusting screws at the rear of the magnets. The lower oscillating end of the vertical beam was arranged to make and break the electrical con-

nection between the oppositely arranged magnets. McCullough stated that in the operation of his motor there was no positive breaking of the current at any point in the vibration of the

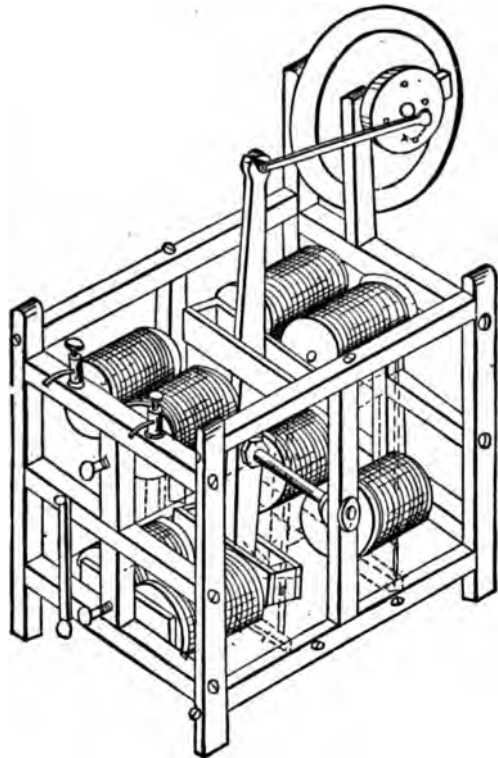


FIG. 33.—McCULLOUGH MOTOR.

central beam, and that as a consequence, there was no loss of the electrical or exciting force upon the magnets.

On April 2, 1867, Chas. J. B. Gaume, of Iowa, patented an electro-magnetic engine of which a side elevation in Fig. 34, and a plan view in Fig. 35 are shown. In the Gaume construction a series of electro-magnets were placed on the periphery of a wheel, and journaled to the same axis was another wheel revolving between the adjacent magnets, carrying a series of armature plates attracted successively. The battery wires were so connected through the motor that a reserve power might be attached or detached by the motion of a governor upon the engine, the speed of which determined the battery connection.

By an inspection of the figures it will be seen that the electro-magnets were mounted upon the horizontal shaft, the wheel carrying the armatures being mounted upon the same shaft,

but revolving in an opposite direction. Each of these wheels carried a bevel pinion, and both meshed with a third bevel gear, mounted upon a vertical shaft, to which the governor was attached. The wires of the electro-magnets were led to the commutator in the usual manner.

Below the armature beams and between the magnets was a supplementary oscillating arm, having pivoted to its outer ends two upright rods, the upper ends of which were attached to the beam which carried the topmost pair of armatures. To the ends of the lower oscillating beam were also pivoted two crank arms or pitmen, the upper ends of which were coupled to the driving shaft by means of crank arms. As all of the series of bars which were operated upon came down as close as possible together within the magnetic field of each pole, the commutator broke the circuit of that series of magnets and closed the circuit of the other series, whereby the other ends of the series of bars were brought into action. In this way an

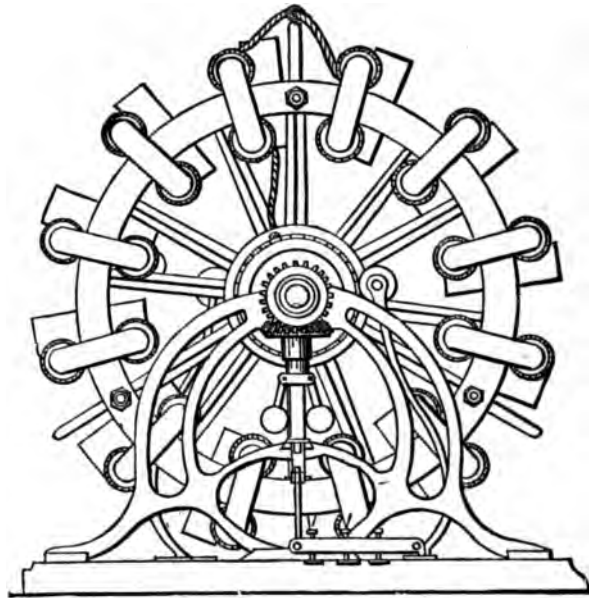


FIG. 34.—GAUME MOTOR.

oscillating motion of the beams was produced, and the upper beam served through its connections to produce a rotary motion of the driving shaft. When the circuit was first closed through the series of magnets the lowest of the corresponding series of armature bars was attracted directly to the magnets, and by its

movement all the other armatures opposite, whose ends rested upon each other, were caused to move a corresponding distance, upon which the lowest bar became magnetic, attracted the second one and drew it down in contact with it, thus giving all the beams a further move-

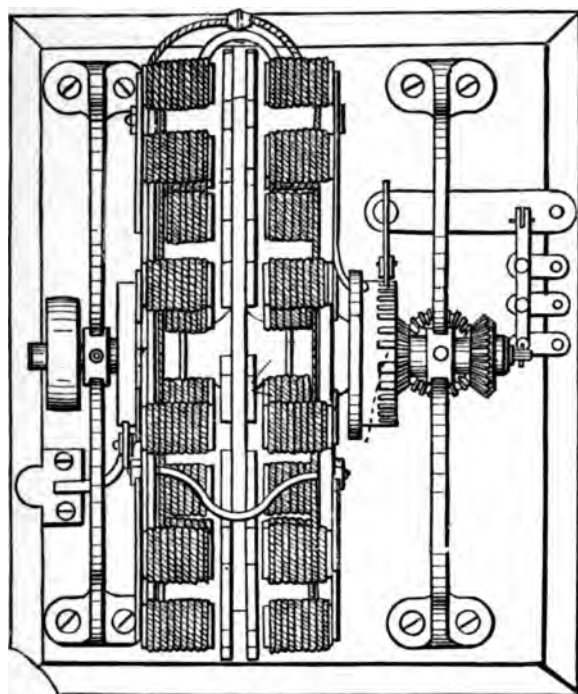


FIG. 35.—GAUME MOTOR.

ment. The second bar, as it came in contact with the first, became magnetic and attracted the third, and so on through the series till all the bars were in contact, as shown in the figure.

The electric governor was of the usual pivoted ball construction, and revolved upon a sliding collar on a vertical shaft rotated by an arrangement of bevel wheels, as before indicated. When the balls rose under increase of speed, a central rod was depressed, raising by an arrangement of levers the horizontal pivoted circuit breaker shown at the bottom of the side-elevation.

This circuit breaker or switch had three keys, which, when the switch was in a horizontal position were in contact with three corresponding plates to which were attached wires from auxiliary batteries. When the governor reached a certain high speed it disconnected one of the keys and consequently one of the sources of electrical power. If the speed still increased, the electrical connection between the second or

central key was broken, and so on. Thus it will be seen, the amount of electrical power was graduated to the speed, the successive connections being severed as the speed increased, and, conversely, being restored when the speed decreased.

As is usual with this type of machine, a determinate impulse in a given direction having been communicated to the wheels, their impetus carried them in the intervals of time when the electric circuit was broken, and the electric impulse being imparted at a certain period, the armatures were individually attracted toward the electro-magnet next in series, and an additional impulse was obtained, producing an increment of speed.

The principal feature of novelty in the electric motor which William Wickersham patented June 2, 1868, and is shown in Fig. 36, was the employment of an endless electro-magnetic chain, the alternate links of which were magnetic bars, the remaining connecting links being non-magnetic. The magnetic links were surrounded by helices through which an electric current passed.

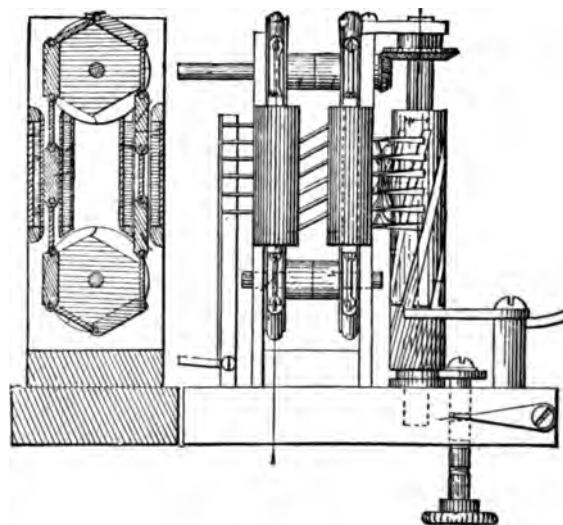


FIG. 36.—WICKERSHAM MOTOR.

The machine itself had two of these endless magnetic chains, arranged vertically on parallel shafts so as to revolve thereon. The bars of the chain, at fixed periods in their revolution, passed through helices having hollow cores.

The strips of metal of which the stationary helices were formed, extended at one end of the motor beyond the helices, and were arranged in parallel lines. A commutator.

consisting of a vertically arranged revolving cylinder, had metal conductors in the shape of strips of metal placed at intervals around it. These conductors were wound spirally, and extended from one end of the cylinder to the other. The extended ends of the helices before referred to were arranged so as to wipe this revolving commutator, and thus close the circuit successively in the different helices. The closing of the circuit in the independent series of coils which constituted the completed helices, was made successively from one end to the other of each helix, and at the same speed that the magnetic endless chain moved in passing through the helices. This was effected by the spiral form of the conductors in the commutator.

The motor was adapted to be stopped or reversed, the commutator being vertically adjustable upon its shaft for this purpose. This commutator, which Wickersham styled a "circuit-cylinder," had a rod arranged in a parallel position with it and passing through the base, by means of which the vertical adjustment of the commutator was accomplished. On the upper end of this rod was secured a freely revolving washer, which rotated within a groove near the lower end of the commutator. The rod itself had three grooves within it, in any one of which the spring stop bolted to the side of the machine could rest. When this rod was raised or depressed, the commutator moved with it and thus was held at any vertical elevation determined by the three grooves in the rod. When the commutator was moved to its highest position the engine ran forward; at its lowest position the commutator reversed the motor, while at its intermediate position the adjustable commutator brought the motor to a state of rest.

The independent coils which constituted the helices were wound in different directions, and each one conducted the electric current around the magnetic link of the endless chain in a different direction from the one preceding it, thereby giving to the magnetic links alternate reversed polarities. When two columns of helices were used on opposite sides of the machine (the magnet chain passing downward through the one and upward through the other), the attraction of the former would be downward and that of the latter upward.

The motor constructed by Charles T. Mason and that made by Mr. A. J. B. DeMorat com-

plete the list of patented motors, the terms of protection of which expired up to the end of 1885, so that our review of some of the early American motors may well end at this point.

Mason's motor, Fig. 37, was designed for driving a fan. It consisted of an electro-magnet, one terminal of the coil of which was connected to the binding post shown in the illustration, and the other to the spindle of the fan shaft. The armature of the electro-magnet is shown pivotally secured to the fan shaft above the electro-magnet. The fan spindle also carried a cam which, as it revolved, broke and

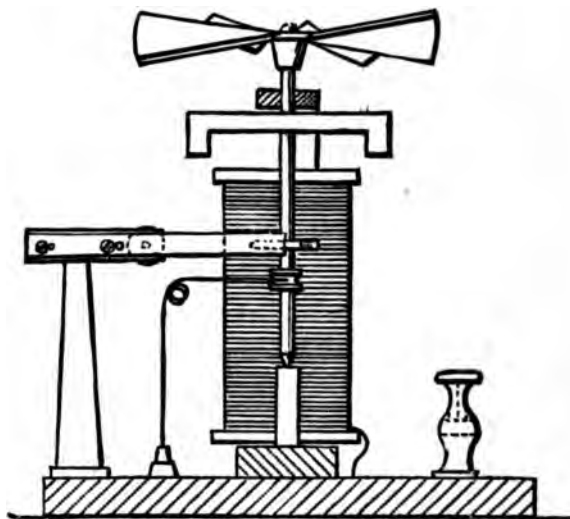


FIG. 37.—MASON MOTOR.

made connection with the horizontal wiping spring secured to a standard at the left of the figure. The cam and wiping spring formed the commutator of the motor.

De Morat's motor is shown in side elevation and in vertical section in Fig. 38. De Morat asserted that there was no interruption or breaking of the current in the use of this motor, such a result never having been practically accomplished before, and that greater velocity, more regular and constant motion, with greater power, could be obtained from his construction than from any other similar machine patented before that date.

By referring to the drawing it will be seen that the lower wheel represents a circular magnet of two or more poles. The central disc of this wheel was of iron, with contiguous coils of wire on either side, the whole being clamped together with wooden discs. The commutator

was also fixed upon the shaft of this circular magnet. It consisted of two metal bands insulated from each other and electrically connected with two wiping springs which completed the circuit.

Above this circular magnet was a wheel of many armatures. This wheel consisted of a number of radial arms which had flanges to receive the separate armatures composing the wheel. Each of these armatures had an independent radial movement within the flanges of the wheel, but without touching the circumference of the same. Each, in addition, had

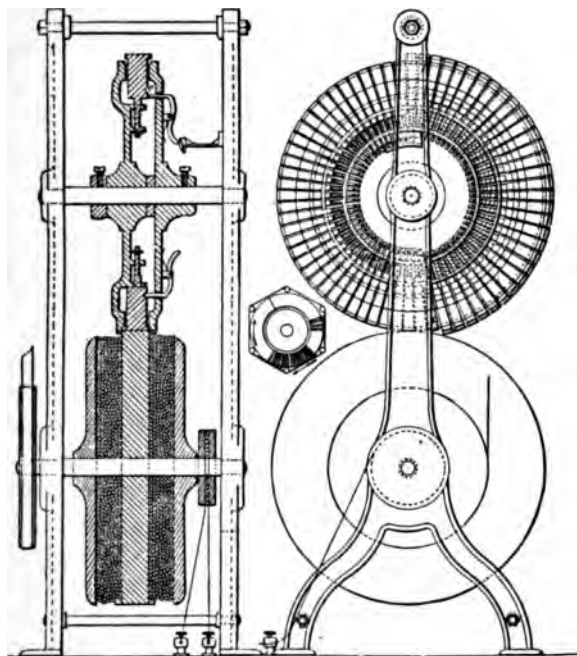


FIG. 38.—DE MORAT MOTOR.

an inward extension stem or shank, which was held in operative position by lugs upon the wheel frame. Coiled springs surrounded these stems between the lugs, and had a constant tendency to force the armatures outward when not held inward by the latches. A projecting arm was bolted to the inner side of one of the standards, on the end of which the outer ends of the latches of the armatures struck. This movement lifted the latches out of the notches in the armatures, and the springs forced them outward, as shown.

As soon as the circular magnet was energized, the armatures were attracted angularly, producing a motion by the tendency to make contact. This was not possible without producing two motions, one causing the system to revolve, the other sending the armatures in-

ward by their contact with the magnet, and fastening them there by the latches dropping into the notches on the armatures. In that position they passed beyond the magnetic field until released by the projection on the frame.

De Morat contemplated reversing the relative arrangement of the motor by converting the armatures into electro-magnets and causing them to exert an attraction on different curves or on a number of planes tangent to the circle in the form of a polygon, as shown in the small sketch representing a hexagon. The attraction would then be effected so as to form an endless chain or elastic band.

It deserves notice that between 1860 and 1867—the period of the civil war—not a single patent was issued in America on electric motors. A war to-day would probably be highly stimulative of inventiveness in this direction. But down to 1860, the interest that had begun to manifest itself twenty years earlier, continued in almost undiminished measure. A lively sketch of the condition of affairs during that period was given by Dr. Vander Weyde in May, 1886, before the New York Electrical Society. Dr. Vander Weyde was commissioned by the late Mr. Peter Cooper to examine the various motors that were submitted by inventors who desired to obtain capital for the furtherance of their work; and it was well for the distinguished philanthropist that he could enjoy the services of one so competent, and of one, too, who by continuous experiments between 1843 and 1848 had already satisfied himself that the electric motor could never be substituted to any extent for other motors so long as the main dependence was upon chemical batteries.

“Invariably I felt obliged to advise adversely,” says Dr. Vander Weyde, “and, while Mr. Cooper was very slow to invest in uncertain enterprises, in some instances a great pressure was brought to bear upon him by enthusiastic inventors and their still more enthusiastic friends, to whom he might have yielded if my convictions, in which he appeared to have much confidence, had not prevented it. Those examinations took place off and on during the whole period of the erection of the Cooper Union building, which was completed in 1859, when I was appointed one of the teachers. I believe Mr. Cooper never spent a single dollar on account of electro-motors, except on such small specimens as were

required for class instruction in the regular course of lectures in physical science given in the Cooper Union building.

"The electro-motors I examined differed greatly in size, from such as occupied scarcely the space of a cubic foot to those of the size of a 50 horse-power steam engine. Among the latter I must mention the motors of three inventors who operated on a large scale, viz., Professor Page, of Washington; Professor Vergnes, of New York, and Mr. Paine, of Newark. I saw Page's engine in operation in New York in 1850. His system is well known among electricians, but deserves special mention for the large scale on which he executed it. It consisted in massive iron plungers which were attracted into coils by alternate currents, and by means of a crank they revolved a fly-wheel. Vergnes' machine was exhibited at our World's Fair in 1852, in the Crystal Palace on Reservoir Square—now called Bryant Park—and consisted in elongated loops of copper wire revolving between the poles of powerful and colossal electro-magnets. In regard to this machine, I will remark that if he had reversed the function of his machine and revolved the loops by means of steam power, he would have had one of the forms of Siemens' dynamos, and would have solved the problem reserved for the investigators of twenty years later (Pacinotti, Gramme and Siemens), who transformed power into electric currents by the inversion of the function of the motor, as Gramme did with Pacinotti's ring. In fact, one of the little motors which I constructed in 1844 would have been a small dynamo, if revolved with sufficient power and velocity.

"For driving their large motors, both Page and Vergnes used proportionally large batteries—large in size as well as in the number of cups. Their batteries were always carefully hidden from view, especially those used by Vergnes, who had in the Crystal Palace several locked rooms which were filled with them.

"Paine, of Newark, did not need any battery at all for exhibition of his motor. He had, however, a small battery connected with his motor, and pretended that this did drive it, together with the circular saw connected with the same. This saw operated with such power that it aroused my suspicions, so I surreptitiously disconnected the battery, and as the saw worked just as well I was convinced that power

was obtained from elsewhere. I then discovered that next door there was a factory where steam-power was used, and that Paine's electro-motor was only on exhibition during the working hours of the factory. The whole deception was clear, the only purpose being to sell stock in Mr. Paine's electro-motor company, which was kept up for several years, but has been put in the shade by the strong vitality of the Keely motor enterprise of the present day."

This chapter should not close without mention of Pinkus, who early conceived an ingenious method of operating an electric railway. Dr. Wellington Adams, of St. Louis, in a paper read in 1884, before the engineers' club of that city, gave some interesting details of the manner in which, when working upon the idea of a railway whose motors picked up their current from the rails, he was referred to the work of his predecessor. "Although at the time (1879) actively engaged in medical practice, and connected with the Medical College in Denver, so great were the allurements, that I was induced to give up everything in Colorado and leave there rather precipitately for Washington, in quest of a generic claim upon this fundamental principle. My case being examined, it was, however, found that the same principle had been proposed and provisionally patented, as far back as 1840, by one Henry Pinkus, a remarkably inventive genius of that period. In 1840, however, the dynamo was unknown, and the electric car motors of Pinkus, which existed only in his imagination, were supposed to be operated by galvanic batteries buried in the ground. The principle of the transmission of the current to the car while in motion for the purpose of effecting its propulsion was, however, the same. The inventor even went so far as to anticipate the future use of 'mechanical generators which should be more economical than the batteries.'" Pinkus was but another of those who were allowed to see the promised land, but were unable to enter. Mention may also be made here of the electric locomotive devised in 1847 by Mr. Lilley and Dr. Colton, of Pittsburgh. This locomotive was driven around a circular track by electricity. The rails were insulated, each connecting with a pole of the battery, and the current was taken up by the wheels, whence it passed to the magnets, upon whose alternate attraction and repulsion motion depended.

CHAPTER IV.

THE ELECTRICAL TRANSMISSION OF POWER.

WHEN Dr. Antonio Pacinotti described his "Electro-Magnetic Machine" in the Italian periodical *Il Nuovo Cimento*, in June, 1864, he mentioned the fact that the machine could be used either to generate electricity on the application of motive power to the armature, or to produce motive power on connecting it with a suitable source of current. This, so far as can be determined, was the first mention of the now so well known principle of the *reversibility* of the dynamo-electric machine, the practical utilization of which implies the development of a new electrical industry—the electrical transmission of mechanical energy.

Probably Dr. Pacinotti himself did not realize that even while he was, for the first time, disclosing the principle of construction that was destined to make the dynamo-electric machine practical and efficient, he was demonstrating this principle of reversibility which promises to multiply the application and utility of dynamo-electric machines tenfold. We mention Dr. Pacinotti's name here purposely to give him the homage due for his valuable researches in this field, especially inasmuch as it was his misfortune to be too far ahead of his time. His researches failed to attract the attention and encouragement which they deserved, and we might say that the same ground had to be travelled over again by those who came later.

The principle of the reversibility of dynamo-electric machines appears to have been perceived by Messrs. Siemens about 1867, but it was not heard of in practical application until the year 1873, when it was practically demonstrated by MM. Hippolyte Fontaine and Breguet at the Vienna Universal Exposition. In this case a Gramme machine used as a motor to work a pump was run by the current produced by a similar machine connected by more than a mile of cable, and put in motion by a gas engine. This was the first instance of elec-

trical transmission of mechanical energy to a distance.

It is always interesting to go back to the first dawn of a new invention, but it is not always easy to determine whether it was the result of accident and necessity, or the outcome of clear, intelligent foresight in the part of an inventor working for a particular purpose. As regards the first transmission of power by electricity, opinions are divided. According to M. Figuier, accident-pure and simple, was the cause of the discovery. He relates that at the International Exhibition of Vienna in 1873, the Gramme Company exhibited two machines intended for plating purposes. One of these machines was in motion, and a workman who noticed that some cables were trailing on the ground, thinking they belonged to the second machine, placed them in its terminals. To the surprise of everybody this second machine, which had been standing still, began to turn of its own accord. Then it was discovered that the first machine was working the second.

This story is romantic, but disappointing to a true lover of science, who would prefer to believe that a great discovery was the logical outcome of the working of a powerful intellect, and not the result of accidental meddling on the part of an ignorant workman. But there is another version of the story, told by M. Hippolyte Fontaine to the Société des Anciens Elèves des Ecoles Nationales des Arts et Métiers. M. Fontaine claims to have actually invented or discovered the electrical transmission of power, as will be seen from the following short abstract of his paper read before the above mentioned society:

"On the 1st of May, 1873—that is, on the date fixed four years previously by imperial decree—the Exhibition in Vienna was formally opened. At that time the machinery hall was yet incomplete, and remained closed to the public until the 3d of June, when it was also

thrown open. I was then engaged with the arrangement of a series of exhibits, shown for the first time in public, which were intended to work together, or separately, as desired. There was a dynamo machine by Gramme for electroplating, giving a current of 400 ampères at 25 volts, and a magneto machine, which I intended to work as a motor from a primary battery, or from a Planté accumulator, to demonstrate the reversibility of the Gramme dynamo. There were also a steam engine of my invention heated by coke, a domestic motor of the same type heated by gas, a centrifugal pump placed on a large reservoir, and arranged to feed an artificial cascade, and numerous other exhibits. To vary the experiments I proposed to show, I had arranged the pump in such a way that it could be worked either by the Gramme magneto machine or by the steam engines (Fontaine).

“On the 1st of June it was announced that the machinery hall would be formally opened by the Emperor at 10 A. M. on the day after the morrow. Nothing was then in readiness, but those who have been in similar situations know how much can be got into order in the space of 48 hours just before the opening of a great exhibition. In every department members of the staff with an army of workmen under their orders were busy clearing away packing cases and decorating the spaces allotted to the different nations. These gentlemen visited all the exhibits in order to determine which of them should be selected for the special notice of the Emperor, so as to detain him as long as possible among the exhibitors of their respective countries.

“M. Roullex-Duggage, who superintended the work in the French section, asked me to set in motion all the machinery on my stand, and especially the two Gramme machines. I set about at once, and on the 2d of June I had the satisfaction of getting the large Gramme dynamo, the two engines (Fontaine), and the centrifugal pump to work; but I failed to get the motor into action from the primary or secondary battery. This was a great disappointment, especially as it prevented my showing the reversibility of the Gramme machine. I was puzzled the whole of the evening and the whole of the night to find a means to accomplish my object, and it was only in the morning of the 3d of June, a few hours before the visit

of the Emperor, that the idea struck me to work the small machine by means of a derived circuit from the large machine. Since I had no leads for that purpose, I applied to the representative of Messrs. Manhis, of Lyons, who was kind enough to lend me 250 metres of cable, and when I saw that the magneto machine was not only set in motion, but developed so much power as to throw the water from the pump beyond the reservoir, I added more cable until the flow of water became normal. The total length of cable in circuit was then over two kilometres. This great length gave me the idea that by the employment of two Gramme machines it would be possible to transmit mechanical energy to great distances. I spoke of this idea to various people, and I published it in the *Revue Industrielle* in 1873, and subsequently in my book on the Vienna Exhibition. The publicity thus given to it was so great that I had neither time nor desire to protect my invention by a patent. I must also mention that M. Gramme has told me that he had already worked one dynamo by the other, and I have always held that the honor of my experiment belongs to the Gramme Company.”

Electric lighting had not yet left the laboratory or the lecture room, and the Gramme machines, then about the only ones made, were all constructed for electrotyping or electroplating, and were consequently ill adapted to the purposes of electrical transmission. However, the demonstration served the purpose of M. Fontaine, its author, for it called attention to this field of study. In 1877 some officers of the French army made use of two Gramme machines to transmit power from a steam engine to a dividing machine, placed at a distance of about sixty metres. Meanwhile, other experimenters were at work in the same direction and it became a lecture experiment to work machinery by an electric motor operated by a current generated at a distance. It was only in 1879, however, that the real importance of the subject was made apparent by MM. Félix and Chrétien in their experiment at Sermaize in plowing by electricity, which was conducted on a practical scale and caused great excitement. At the same time, 1879, the electrical railway of Siemens and Halske, which made its first appearance at the Berlin Exhibition, was an interesting and perhaps still more striking instance of the possibilities of the electrical

transmission of power. The electrical exhibition of 1881 at Paris also afforded to electrical engineers an excellent opportunity to demonstrate the applicability of electrical transmission in providing motive power for multifarious purposes. The currents from dynamo-electric machines were used for driving motors for sewing machines, lathes, planers, drills, hammers and other workshop machinery, rock-drills, saws, pumps, elevators; and also for electric railways, one of which, from the firm of Siemens & Halske, served to convey passengers from the Place de la Concorde to the Palais de l'Industrie.

At the Munich Exposition in 1882 the subject of the electrical transmission of mechanical energy did not fail to receive a share of attention. There were several practical examples showing the production of motive power from electricity.

Our illustration, Fig. 39, represents one of these installations, a small workshop, which derived its motive power from a Schuckert machine fed from a similar machine placed in another part of the Crystal Palace and run as a generator. M. Schuckert had also another installation for demonstrating the transmission of mechanical energy by electricity. In this case the generator was placed at Hirschau in a machine shop supplied with water power from the Isar River. The motor was in the Crystal Palace, and the distance between the two was about ten kilometres. The conductors were two wires of copper, four millimetres in diameter (= No. 6 B. and S.) and had a total resistance of 9.6 ohms. The power expended on the generator was of about nine horse, and the work done by the motor, which was belted to a counter-shaft furnishing power to two threshing machines running empty, was equal to about three horse power. The efficiency was therefore about one-third.

In another installation, the Edison "Z" machine was used as a motor to supply motive power to a German "Melkerei," or dairy, such as is frequently to be seen in the mountains in Bavaria, where the power of water-falls is made to move the churns, skimmers and other contrivances.

But there was another example—we might say proof—of the possibilities of electrical transmission of energy to a distance, which made the Munich Exposition itself memorable, and com-

pared with which all other previous ones paled into insignificance. We refer to the celebrated feat of electrical transmission of M. Marcel Deprez. The science of electrical transmission of energy over long distances may be said to date from that time, for it was in these experiments that M. Deprez revealed to the electrical world the theory of electrical transmission deduced by himself, while he furnished a proof by ocular demonstration. It is for this reason that the name of Marcel Deprez occupies such an important space in all discussions bearing on this subject.

We may omit the consideration of M. Deprez's particular theories for the present, however, in order to point out generally what are the principles entering the problem of the distribution of power by electricity, the most of which were first demonstrated by Siemens and Deprez.

To convey energy by means of electricity from one place to another, three things are necessary: a generator, a motor, and two conductors connecting both. The generator converts energy out of its mechanical form (or chemical, caloric) into electric energy; the motor reconverts it into its mechanical (chemical, caloric) form. But not all the electric energy produced by the generator will be reconverted by the motor, as it is a well known fact that if a current pass through a circuit a certain amount of its energy will appear as heat, as no circuit can be made without resistance. If then W stands for the work expended upon the generator, w for that done by the motor, and if HJ be the mechanical value of the heat generated (J stands for Joule's equivalent and H for the number of heat units), then, according to the law of conservation of energy first enunciated by Helmholtz:

$$W = HJ + w. \quad (\text{I.})$$

Now, if the electromotive force of the generator be E , and the resistance of the circuit, including generator, motor, and conductors be R , then a current C would have to pass through the circuit, and, according to Ohm's law,

$$C = \frac{E}{R}.$$

And this is also the case as long as the motor stands still; but as soon as its armature rotates, *i. e.*, the motor does work, the current C sinks

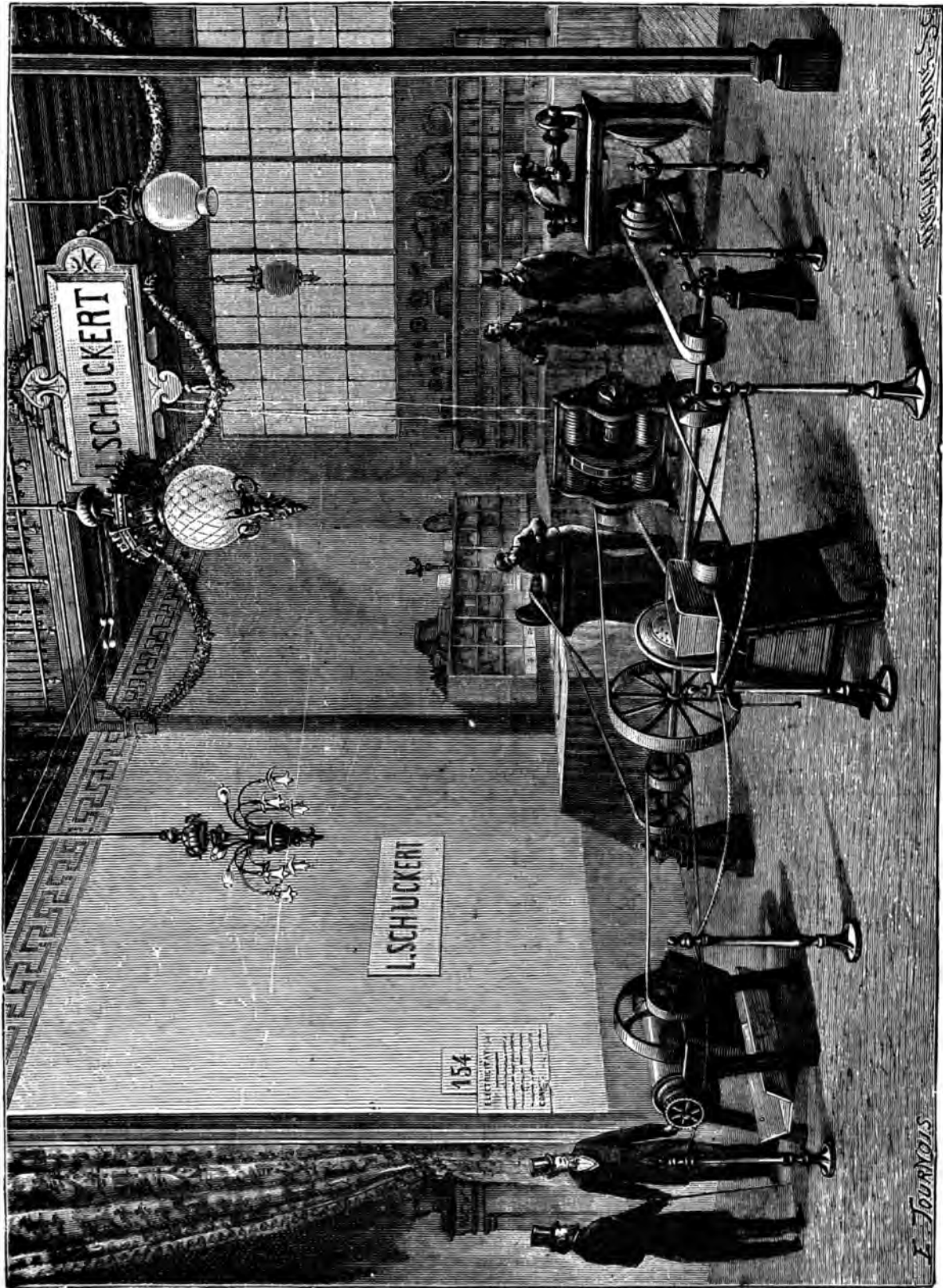


FIG. 39.—SCHUCKERT INSTALLATION AT THE MUNICH EXPOSITION OF 1882.

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to C_1 . Now, as no new resistance has been added to the circuit, the cause of this falling of current can only be an electromotive force, induced by the magnets of the motor in the rotating coils of the armature, and opposing the electromotive force of the generator. C_1 can therefore be expressed by the formula:

$$C_1 = \frac{E - e}{R} \quad (\text{II.})$$

in which e stands for the counter electromotive force.

In the preceding and subsequent formulas Mr. H. M. Schlesinger, in following Professor S. P. Thompson, has assumed the generator and motor to be such as to convert mechanical energy into electric, and *vice versa*, without loss; the sources and effect of such loss will be considered later on.

Formula (II.) may also be written in the following manner:

$$E = e + C_1 R,$$

or $E C_1 = e C_1 + C_1^2 R. \quad (\text{III.})$

But the work done by a dynamo can be expressed by the product of its electromotive force and the current it generates, and, according to Joule, the heat generated in a circuit is proportional to the square of the current passing through it and to its resistance. We can therefore put

$$W = E C_1, \text{ and } H J = C_1^2 R.$$

Equation (III.) can then be written

$$W = e C_1 + H J.$$

On comparing this with (I.) we get:

$$e C_1 = w. \quad (\text{IV.})$$

Or substituting the value of C_1 found in equation (II.),

$$w = e \frac{(E - e)}{R} \quad (\text{IVa.})$$

or the work done by the motor is equal to the product of the current flowing through the circuit and the counter electromotive force the motor has set up.

Referring to (II.), we find that if E and R be constant, C_1 is a function of e , for any change of e produces a change of C_1 . Now, as $e C_1$ is the expression for the work done by the motor,

the question is, for what current will $e C_1$ be a maximum? To find this maximum, we will write (III.):

$$e C_1 = E C_1 - C_1^2 R;$$

and employing the differential calculus for the sake of brevity we get by placing the first differential coefficient equal to zero:

$$\frac{d e C_1}{d C_1} = E - 2 R C_1 = 0,$$

or $E = 2 R C_1;$

but, according to (I.), $E = R C,$

therefore $C_1 = \frac{C}{2},$

and as $C_1 = \frac{E - e}{R} = \frac{C}{2},$

$$E - e = \frac{1}{2} R C = \frac{1}{2} E,$$

$$e = \frac{1}{2} E.$$

That is, if the counter electromotive force is such that the current flowing through the circuit is just one-half of the current which would flow through it if the motor did no work, the motor will be doing most work for unit time;

for any other current larger or smaller than $\frac{C}{2}$

the amount of work done within unit time will be less.

This law, generally called the law of maximum activity, was discovered by Jacobi. Although as we have pointed out in a previous chapter it has *nothing whatever to do with the efficiency of transmission*, it has often been mistaken for the law governing the latter; and as in case of maximum activity the efficiency of transmission is 50 per cent., it has been said that the highest efficiency of the system is only 50 per cent. This is entirely wrong, as the efficiency can be made as high as one likes. This will be seen later on.

Jacobi's law can easily be proved by an example. Let $E = 100$; $R = 10$; then $C = 10$, and for $C_1 = 5$, $e = 50$; as deduced from eq. (II.)

the work done by the generator is $E C_1 = 500$ watts, the work done by the motor is $e C_1 = 250$. If $C_1 = 6$, then from (II.)

$$E - e = R C_1,$$

or $100 - e = 60$; therefore, $e = 40$;

$$E C_1 = 600, e C_1 = 240.$$

If $C_1 = 4$, $e = 100 - 40 = 60$,

and $E C_1 = 400, e C_1 = 240$.

(This also proves what has been said about

the efficiency, as in the first case $\eta = \frac{250}{500} = \frac{1}{2}$;

in the second $\eta = \frac{240}{600} = \frac{2}{5}$; and in the last case

$\eta = \frac{240}{400} = \frac{3}{5}$.) The Greek letter η stands for the

efficiency of transmission.

In his work on dynamo-electric machinery, Prof. S. P. Thompson has given diagrams to show this law graphically. Our equation (II.) is

$$C_1 = \frac{E - e}{R}$$

and $E C_1 = W_1, e C_1 = w$;

we can then write

$$W = \frac{E(E - e)}{R} \text{ and } w = e \frac{(E - e)}{R},$$

and as R is a constant we get the relative values,

$$E(E - e) \text{ and } e(E - e).$$

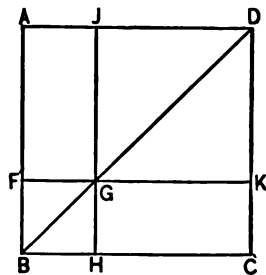


FIG. 40.

Let us now construct a square at $A B C D$, Fig. 40, the side of which is equal to E , and measure out from the point B the counter electromotive force $e = B F$, draw $F K$ parallel to $B C$ and through the point G , in which $F K$ intersects the diagonal $B D$, draw $J H$ parallel to $B A$. The rectangle $A F K D$ will now repre-

sent the work done by the generator, as $A F = E - e$ and $F K = E$, and the rectangle $G H C K$ represents the work absorbed by the motor, as $G H = e$ and $H C = E - e$.

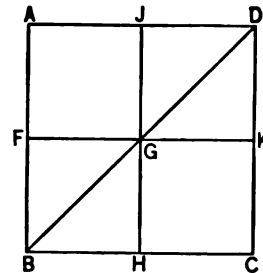


FIG. 41.

According to a well-known geometrical law the rectangle $G H C K$, Fig. 41, will be a maxi-

mum for $G B = G D$; then $B F = \frac{A B}{2}$; that is

$e = \frac{E}{2}$, and as was shown above, if the counter

electromotive force is half the electromotive force, the current passing through the circuit is one-half of the current which would pass if the motor were standing still. The square $G H C K$ representing w is

$$G H C K = w = e(E - e) = \left(\frac{E}{2}\right)^2 = \frac{1}{4} E^2.$$

The rectangle $A F K D$ represents W or

$$A F K D = W = E(E - e) = \frac{1}{2} E^2 = 2 w.$$

According to this diagram, then, the motor will do most work in unit time when the counter electromotive force is one-half of the electromotive force, the current at the same time being one-half of the current which would flow through the circuit if the motor was standing still.

As we pointed out before, and as formulas (I.), (II.), (III.) and (IV.) show, not all the work put into the generator will be recovered through the motor. In the following, both generator and motor are still assumed to be perfect—that is, transforming energy of one form into another without loss. Of course, in practice this will not be the case, but the nature and amount of such losses are known to all good dynamo-makers, who, therefore, also know by what means they can be brought down to the lowest limit. Moreover, it will be very difficult, if not

even quite impossible, to give formulas covering all these sources of loss. But, aside from these losses, part of the energy is lost in the circuit, being that part which is necessary to force the current through the circuit. The rest of the energy will appear as useful work in the motor (assumed to be perfect). Now, the efficiency of any system is the ratio of the useful work to that spent in producing it; that is, if η stand for the efficiency of transmission,

$$\eta = \frac{w}{W}, \text{ and in our case}$$

$$\eta = \frac{w}{W} = \frac{e C_1}{E C_1}; \text{ that is}$$

$$\eta = \frac{e}{E}. \tag{V.}$$

According to this equation, the efficiency of transmission is as the ratio of the electromotive forces. This again shows that Jacobi's law of maximum activity has nothing to do with the efficiency. The counter electromotive force e can range between the limits $e = 0$ and $e = E$, at the same time η will range between $\eta = 0$ and $\eta = 1$. If $e = 0$, then $\eta = 0$ also; if $e = \frac{1}{2} E$,

then $\eta = \frac{1}{2}$; if $e = E$, then $\eta = 1$. In the

first case, the motor will be doing no work, as the energy put into the generator will be lost in heating the wires of the circuit. With e the efficiency will gradually rise, and at the same time the actual work got out of the motor in

unit time till $e = \frac{E}{2}$, at this point $\eta = \frac{1}{2}$; that

is, half the energy put into the generator is lost as heat in the circuit; the other half

appears as useful work, and for $e = \frac{E}{2}$ also,

the motor will be doing most work. As e continues to rise, η does the same, but at the same time the work done per unit time sinks again, till $e = E$. Now, $\eta = 1$, but the motor will be doing no work, and theoretically the generator ought to require none either; but in practice this is impossible, as e can never

rise so high that $e = E$. The cause of this is the resistance of the circuit, and, of course, the mechanical resistance of the armature, such as friction, etc. In practice, it is difficult to measure the counter electromotive force e (e must not be confounded with the difference of potential at the terminals of the motor); it is more convenient to measure the current flowing through the circuit and the difference of potentials at the terminals of the generator, and, knowing the resistance of the generator and the other part of the circuit, the electromotive force of the generator is easily found, and equation (II.) will give the counter electromotive force.

These relations between counter electromotive force, efficiency, and work per unit time, can very easily be shown graphically with the diagram used by Thompson. Let AB , Fig. 40, again be equal to E , $FB = e$, and the lines $FJKH$ drawn as before; then, R being constant:

$$AFKD = E(E - e) = W$$

$$GHCK = e(E - e) = w.$$

The efficiency of transmission will then be as the ratio of these rectangles, and the work lost in heating the circuit will be represented by $JGKD$, as $AFGJ$ is equal to $GHCK$.

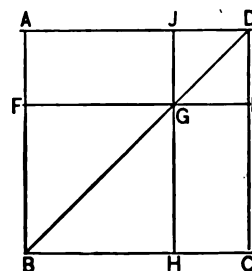


FIG. 42.

This diagram, therefore, represents a case in which either the load put on the motor is too large or the armature not properly geared to the rest of the working parts (in an electric locomotive, to the wheels). The result is that the armature of the motor cannot move with the necessary speed, and therefore the counter electromotive force is very low. Fig. 42 is the diagram of another case; AB again is equal to E , $BF = e$. The work spent in the generator is, therefore, again represented by the rectangle $AFDK$, and the useful work by $GHCK$. It is easy to see that in this case the efficiency

represented by the ratio of the two rectangles is far superior to that represented by Fig. 40. Whereas in Fig. 40 FB is $\frac{1}{3}$ of AB (i. e., $E = 3e$), and in consequence rectangle $GHCK$ is one-third of $AFKD$, the efficiency being therefore $\eta = \frac{1}{3}$, in Fig. 42 FB is two-thirds of AB (that is, $2E = 3e$), and, therefore, rectangle $GHCK$ is $\frac{2}{3}$ of rectangle $AFKD$, making the efficiency $\eta = \frac{2}{3}$. In this case, therefore, although only *half the work* has been put on the generator, the motor is doing *exactly the same amount of work* as in the case represented by Fig. 40.

In the expression for the efficiency

$$\eta = \frac{e}{E},$$

there is no term representing the resistance R . This proves clearly that theoretically there is no limit for this system of transmission, and that the resistance of the circuit, or, what amounts to the same thing, the distance between the two

stations, may be ever so large; so long as $\frac{e}{E}$ is

kept constant, the efficiency will always be the same. In practice, of course, a limit exists, because if we make R larger, keeping E and (in order to have the same efficiency) e constant, a smaller current would flow through the circuit, as will be seen by referring to equation (II.)

This equation may be written

$$C_1 R = E - e;$$

E and e being the same, $E - e$ is constant; altering R , therefore, will also alter C_1 . The result is, that $E C_1$ would be smaller than before, and, consequently, if the resistance is made larger, the electromotive forces will also have to be increased.

Again, if we keep the resistance constant, but alter the electromotive forces, keeping $E - e$ constant, then, according to equation (II.) the current C_1 will be constant too. In equation (III.) the term $R C_1^2$ represents the amount of energy lost as heat in the circuit, and as it only involves R and C_1 , it follows that if these remain the same, the former will not vary with the varying electromotive forces. But, on the other hand, making E and e larger also makes the amount of energy transmitted and the amount transformed into useful work larger. Fig. 43 shows this graphically.

On comparing it with Fig. 42, it will be found that $JGKD$, representing the heat wasted, is the same in both cases, but the rectangles $AFKD$ and $HGKC$ are larger in Fig. 43 than in Fig. 42. More energy has, therefore, been transmitted; but as the losses are the same, the efficiency in the case represented by Fig. 43 is larger than in that represented by

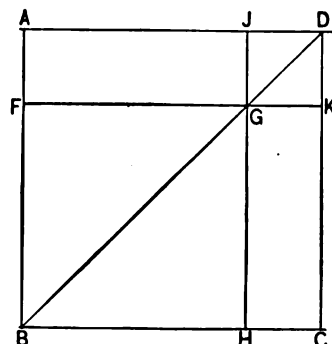


FIG. 43.

Fig. 42. The amount of energy, therefore, that can be transmitted over a circuit having a given resistance is again theoretically without limit, and the larger the amount of energy transmitted the larger will be the efficiency of transmission, if $E - e$ is kept constant.

Let E , for example, be 200 volts, $e = 150$ volts, and $R = 10$ ohms;

then $E - e = 50$

and $C_1 = \frac{200-150}{10} = 5$ ampères.

The amount of energy put into the generator is

$$W = E C_1 = 1000 \text{ watts};$$

the useful work is

$$w = e C_1 = 750 \text{ watts};$$

energy lost as heat,

$$HJ = R C_1^2 = 250 \text{ watts};$$

the efficiency is

$$\eta = \frac{e}{E} = \frac{150}{200} = \frac{3}{4}.$$

Now let $E = 400$ volts, $e = 350$ volts, and R again = 10 ohms;

then

$$E - e = 50.$$

$$C_1 = \frac{400-350}{10} = 5 \text{ ampères.}$$

$$W = E C_1 = 2000 \text{ watts.}$$

$$w = e C_1 = 1750 \text{ watts.}$$

$$HJ = R C_1^2 = 250 \text{ watts,}$$

$$\text{and } \eta = \frac{e}{E} = \frac{350}{400} = \frac{7}{8}.$$

We have now put into the generator double the amount of energy; of this the same amount is lost in heating the circuit, and the efficiency has risen from $\frac{3}{4}$ to $\frac{7}{8}$.

This clearly shows that it is always more economical to use small currents with high electromotive forces, the more so since the higher the electromotive force the greater the resistance can be made without altering the efficiency, and the less will be the cost of the circuit.

Up to the present we have assumed that only that amount of energy is lost which appears as heat in the circuit; but there is another source of loss due to the leakage of current between the two conductors. With currents of low tension this is not perceptible, as the insulation can easily be made perfect; but on long lines and with high electromotive forces this loss may be so large as to lower the efficiency somewhat.

It will now be necessary to say a few words about the resistance and efficiency of the different parts of the circuit. The circuit consists of three different parts, and they are: the generator, the conductors, and the motor. Letting r_1 stand for the resistance of the generator, r_2 for that of the conductors, and r_3 for that of the motor, then the resistance of the circuit will be:

$$R = r_1 + r_2 + r_3.$$

Let l_1 , l_2 , l_3 stand for the losses of energy in these different parts, then we will have:

$$l_1 = C_1^2 r_1,$$

$$l_2 = C_1^2 r_2,$$

$$l_3 = C_1^2 r_3,$$

and the efficiency will be: $\eta = \eta_1 \times \eta_2 \times \eta_3$, and

$$\eta_1 = \frac{E C_1 - C_1^2 r_1}{E C_1} = \frac{E - C_1 r_1}{E};$$

$$\eta_2 = \frac{E C_1 - C_1^2 r_1 - C_1^2 r_2}{E C_1 - C_1^2 r_1} = \frac{E - C_1 r_1 - C_1 r_2}{E - C_1 r_1}$$

$$\eta^3 = \frac{E C_1 - C_1^2 r_1 - C_1^2 r_2 - C_1^2 r_3}{E C_1 - C_1^2 r_1 - C_1^2 r_2} = \frac{E - C_1 r_1 - C_1 r_2 - C_1 r_3}{E - C_1 r_1 - C_1 r_2}$$

But $C_1 r_1$ is the electromotive force necessary to force a current C_1 through a resistance r_1 ; $E - C_1 r_1$ will therefore be the difference of potential at the terminals of the generator, and for similar reasons $E - C_1 r_1 - C_1 r_2$ will be that at the end of the conductors or terminals of the motor. On the other hand, $C_1 r_3$ gives the loss of electromotive force due to the resistance of the wire on the motor, but the electromotive force at this end of the circuit has already been shown to be equal to e , and if e_1 and e_2 , respectively, stand for the other two, then we have:

$$\eta_1 = \frac{e_1}{E}, \quad \eta_2 = \frac{e_2}{e_1}, \quad \eta_3 = \frac{e}{e_2},$$

and

$$\eta = \frac{e_1}{E} \times \frac{e_2}{e_1} \times \frac{e}{e_2} = \frac{e}{E}.$$

We have seen from equation (V.) that the efficiency of transmission is as the ratio of the electromotive forces of the generator and re-

ceiver *i. e.*, $\frac{e}{E}$. As this expression does not con-

tain the factor of resistance R , of the line or machines, M. Deprez was led to promulgate the theory that *in the electrical transmission of energy the efficiency is independent of the distance of transmission*. This theory, first started in March, 1880, has provoked considerable discussion. It means, in effect, that we can make the distance, and hence the resistance of the line, whatever we please without loss of efficiency.

We cannot here enter into a full discussion of this view, but we may say briefly, that as a *theory*, pure and simple, the proposition is correct, as was developed in the preceding pages. But there are practical difficulties which prevent its realization, and it would be dangerous to apply it in the calculations of a working enterprise. It is evident that the quantity of heat generated in a conductor by the electric current ought to increase with the length of the wire, and hence the loss would increase. On the other hand, M. Deprez argues that the production of heat varies as the square of the intensity of the current, and that the latter is diminished by an increase of the length of the line.

The question suggests itself: How can the evil effects of increased distance be obviated?

We have seen by equation (IV. a) that the useful work of the motor is equal

$$\frac{e(E-e)}{R}$$

This equation shows that there are two ways of overcoming the difficulties of long distance transmission of a given power. Thus we can either diminish R , the resistance of the conductor, by increasing its diameter; or we can increase the relative electromotive forces of the machines.

The first method, that of increasing the size of the conductor, was first proposed by M. Maurice Levy, in February, 1882, in a note to the French Academy of Sciences, wherein he says that "the resistance of the exterior circuit can be made very small, even for long distances, by employing a very large wire." Evidently, this would be an easy way out of the difficulty if it were not for the fact that any increase in the size of the conductor means increased cost, and hence, starting from an economical standpoint, we soon reach a limit in the size of conductor that can be used.

The second method of overcoming the difficulties of long distance transmission, as we have seen above, consists in increasing the electromotive forces of the machines. This is the method developed by M. Marcel Deprez and consists in employing *high tension* currents. According to M. Deprez, in order to obtain the same useful work, whatever be the length of the line, it suffices simply to vary the electromotive forces of the machine proportionally to the square root of the resistance of the circuit. In other words, if, as before, R represents the resistance of the circuit, and E and e , respectively, the electromotive forces of the machines, and in such a circuit we obtain useful work at the motor w , then, in order to obtain the same amount of work with other values, R^1 , E^1 , e^1 , it is necessary to make the new values E^1 and e^1 such, that they will satisfy the following equations:

$$\frac{E^1}{E} = \sqrt{\frac{R^1}{R}}, \quad (\text{VI.})$$

$$\frac{e^1}{e} = \sqrt{\frac{R^1}{R}}. \quad (\text{VII.})$$

Or if we let w^1 represent the work produced in the second case, we have:

$$w = \frac{e(E-e)}{R},$$

$$w^1 = \frac{e^1(E^1-e^1)}{R^1}.$$

Substituting now in the latter equation the values of E^1 and e^1 developed from equations (VI.) and (VII.), we get:

$$w^1 = \frac{e \sqrt{\frac{R^1}{R}} \left(E \sqrt{\frac{R^1}{R}} - e \sqrt{\frac{R^1}{R}} \right)}{R^1} = \frac{e \frac{R^1}{R} (E-e)}{R^1}$$

$$\therefore w^1 = \frac{e(E-e)}{R} = w.$$

Before describing the experiments made by M. Deprez to demonstrate this theory we must allude to another form in which according to M. Deprez the efficiency of transmission can be expressed; and that is, that the efficiency is equal to the ratio of the speeds respectively of generator and motor. Calling N the former, and n the latter, the efficiency would be expressed by,

$$\frac{n}{N}$$

This, of course, assumes that the two machines are identical, that the magnetic field and the current are the same in intensities in both, and hence that the electromotive forces developed are proportional to the speeds of the armatures. This, however, is not the case if there is any leakage along the line, for then not all the current developed by the generator passes through the motor. Moreover, as Prof. S. P. Thompson points out, when there are resistances in the line, the ratio of the electromotive forces of the machines is not the same as the ratio of the two differences of potentials, as measured between the terminals of the machines.

Further, even though the current running through the armatures and field magnets in the generator which creates the current, and in the motor which utilizes the current, be absolutely

identical, the intensities of the magnetic fields of the two machines are not equal,—even though the machines be absolutely alike in build; because the reaction between the armature and the field magnet is entirely different in the dynamo used as a motor from that in the dynamo which is being used as a generator.

As we have stated above, M. Deprez, by employing high electromotive forces, seeks to diminish the current, and thus to diminish the heat which it generates in the conductor to such an extent that it shall be inappreciable.

His experiments to demonstrate the truth of his theory are very interesting, and of great value from a scientific standpoint.

The first real *long distance* transmission was undertaken by M. Deprez at the Munich Electrical Exhibition of 1882, with two Gramme machines. These were placed respectively at Munich and at Miesbach, a distance apart of 57 kilometres (37 miles). They were connected by an ordinary iron telegraph wire, 4½ mm. in diameter, and constituted a complete metallic circuit 114 kilometres (74 miles) in length. The resistance of the line measured 950.2 ohms; that of the generating machine at Miesbach 453.4 ohms; and that of the motor at Munich 453.4.

The generator was placed in the workshop of Herr Fohr, and appeared as shown in the illustration, Fig. 44. The motor was placed in the Munich Crystal Palace, and was belted to a centrifugal pump which fed a cascade nearly three metres in height, as illustrated in Fig. 45. The measurements taken by the committee were as follows:

Speed of generator at Miesbach,	1611 revolutions.
Intensity of current at "	0.519 ampère.
Speed of motor at Munich,	752 revolutions.
Difference of potential at terminals of motor, 850 volts.	
Work measured by brake at motor,	0.25 H. P.

From these data the following values were calculated:

Difference of potential at terminals of generator,	1343 volts.
Total electrical energy at Miesbach,	1.13 H. P.
Total electrical energy at Munich,	0.493 H. P.
Electrical efficiency,	38.9 per cent.

It will be understood here that this efficiency is not the *absolute* or commercial efficiency, but the *electrical* alone. We must explain this by an example. If, for instance, in the above case, all the power applied to the generator had

been converted into electrical energy, or, in other words, if the generator were a perfect machine; and if the motor had converted all the electricity into useful work, then the efficiency would have been that given, viz., 38.9 per cent. The absolute efficiency of a system is the ratio of the power applied to the generator to that obtained from the motor. It thus includes not only the electrical efficiency but that also of the motor and generator, as con-

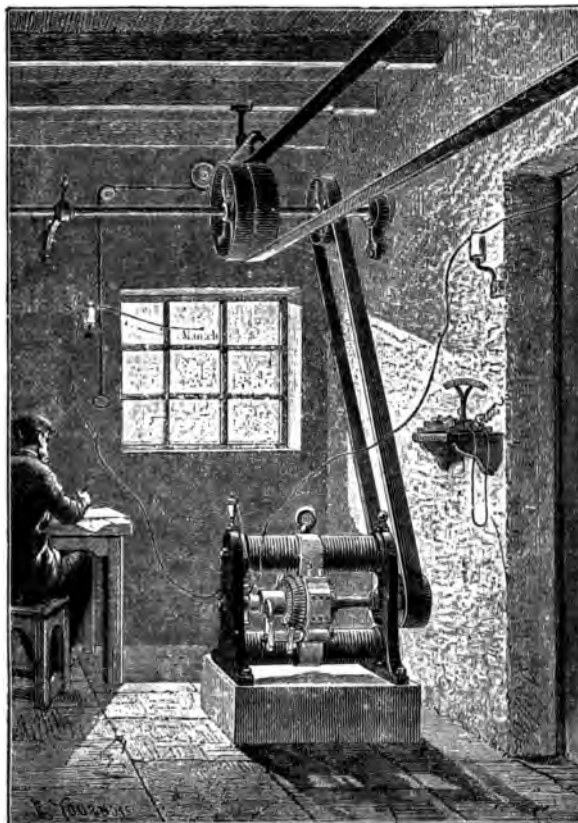


FIG. 44.—DEPREZ GENERATOR AT MIESBACH.

verters of energy. Thus, in the above experiment, while the electrical efficiency was 38.9 per cent., the absolute efficiency must have been less. Exactly how much less this was we have no means of telling, because the power applied to the generator at Miesbach was not measured. But if we assume the efficiencies of the motor and generator each to have been 85 per cent., we would have for the *absolute* efficiency of the transmission $0.85 \times 0.85 \times 38.9$ or about 28 per cent.

M. Deprez, however, did not rest contented with these experiments, but followed them up

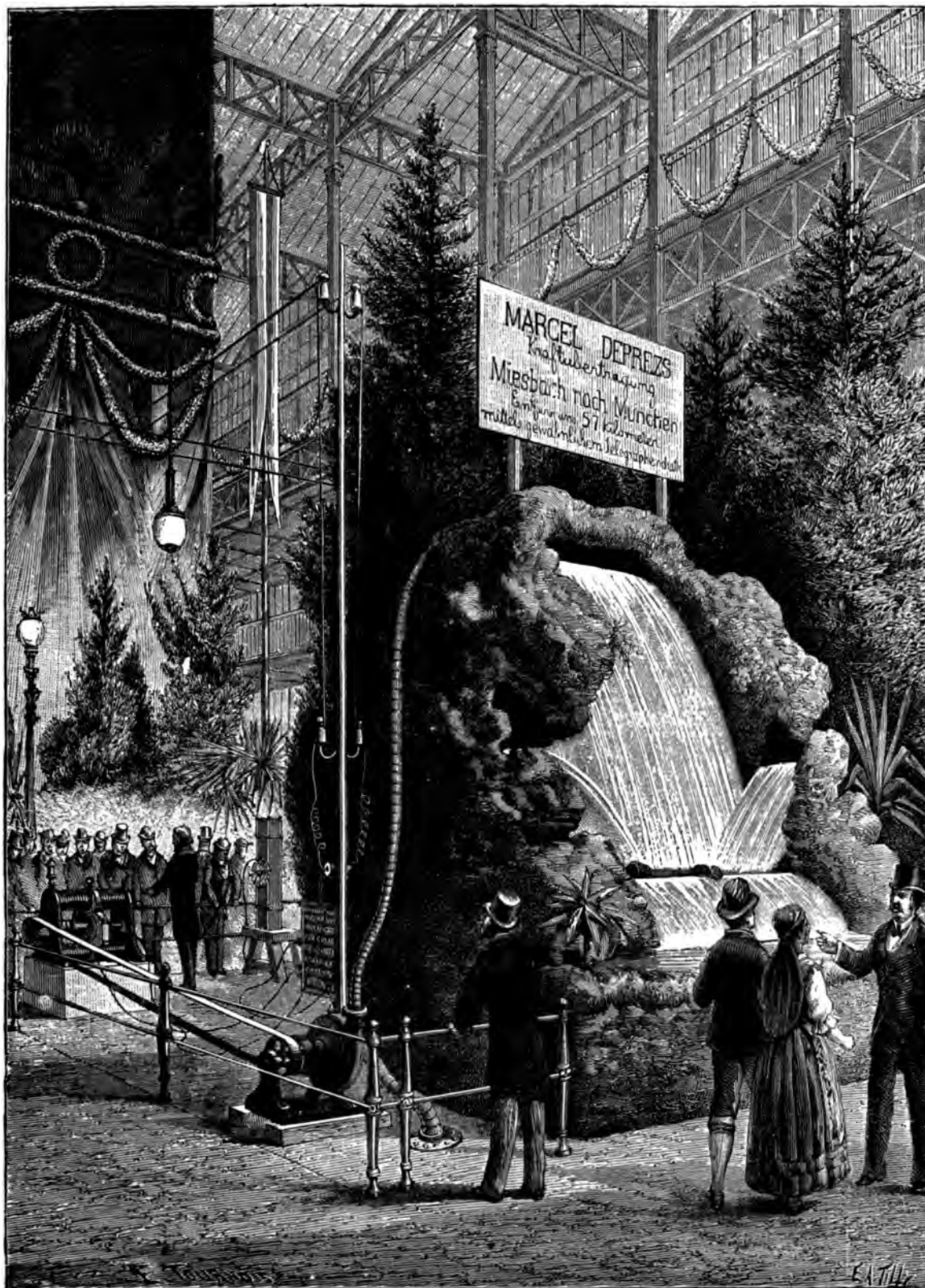


FIG. 45.—DEPREZ INSTALLATION AT THE MUNICH EXPOSITION, 1882.

by others in 1883 from the depot of the Chemin de Fer du Nord, Paris, to La Chapelle, a distance of 8,500 metres—about $5\frac{1}{4}$ miles; and another from Vizille to Grenoble, a distance of 14 kilometres ($7\frac{1}{2}$ miles). The generator used is shown in Fig 46. The most recent, and perhaps the most important, of M. Deprez's experiments in long distance transmission was undertaken in October, 1885, and the object aimed at was to demonstrate the practical application and distribution of power transmitted over a long distance. For this purpose the apparatus was

metres from each other. Each possessed, like the generator described below, two rings; they were each 0.58 metre in exterior diameter and had an electric resistance of 18 ohms.

Our illustration, Fig. 47, shows one of the generators.

In the generating machine the field is produced by 8 electro-magnets of horseshoe form, and the pole pieces embrace the armatures over very nearly their entire circumference. The field is excited by a separate dynamo, and the current is passed through the different electro-

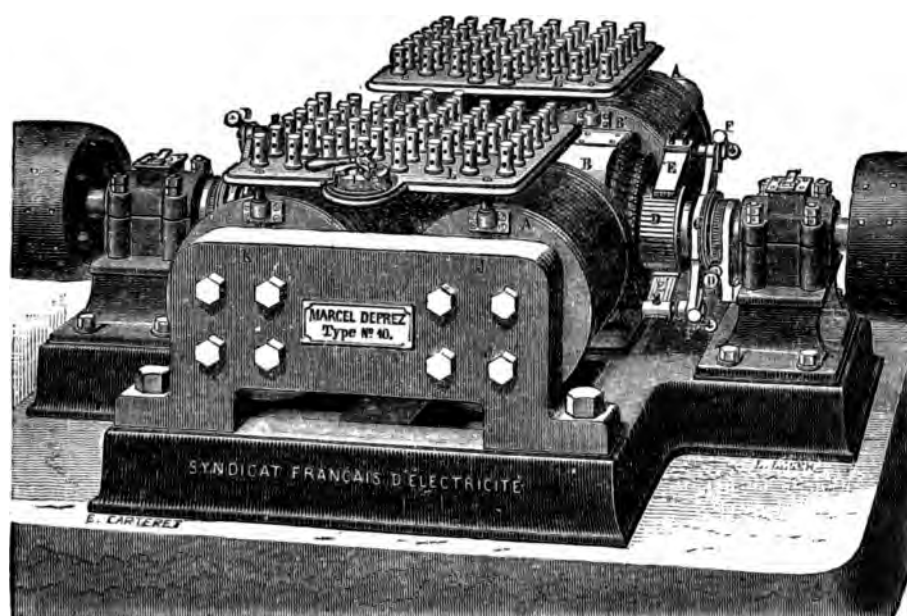


FIG. 46.—DEPREZ GENERATOR AT THE CHEMIN DE FER DU NORD, PARIS, 1883.

intended to operate electric light machines, to drive pumps and to run machine tools at the company's workshops.

The distance from Paris to Creil, between which two points the line extended, is 56 kilometres (34 miles), making a total length of conductor of 68 miles. The line consisted of a lead-incased insulated copper wire 5 mm. in diameter, and its resistance was 100 ohms.

The generating machine was situated at Creil. It had two rings revolving in two distinct magnetic fields, each composed of eight electro-magnets. Each armature had a resistance of 16.5 ohms.

The current produced by this machine was utilized at La Chapelle, near Paris, by two receiving machines, situated at some hundreds of

magnets so that a north pole on one side of the armature is opposite a south pole on the other.

The total weight of each of the electro-magnets is 485 kilogrammes. They are wound with copper wire $2\frac{1}{4}$ millimetres in diameter. The wire is covered with two layers of silk, one of cotton, and finally with a layer of shellac. The total length of wire wound on the magnets is 56,496 metres. The winding is done in sections, each having the form of a flat ring. Each section is composed of 11 layers of 25 convolutions each. The core of each electro-magnet carries 12 of these sections, and the ends of the wires are led to the terminal boards, so that they can be coupled up in any manner desired. The resistance of each section is 1.06 ohm, and the

total resistance of the magnets grouped in series would be 203.52 ohms.

The radius of the pole pieces is 710 mm. and their thickness 120 mm. All the pole pieces on the same side of a horizontal plane passing through the shaft are in magnetic communication with one another.

wire is $2\frac{1}{2}$ millimetres in diameter and insulated in the same way as the magnet wire. The following are the principal dimensions and weights:

No. of sections per segment,	21
Total No. of sections,	231
Length of wire per section,	52 metres.

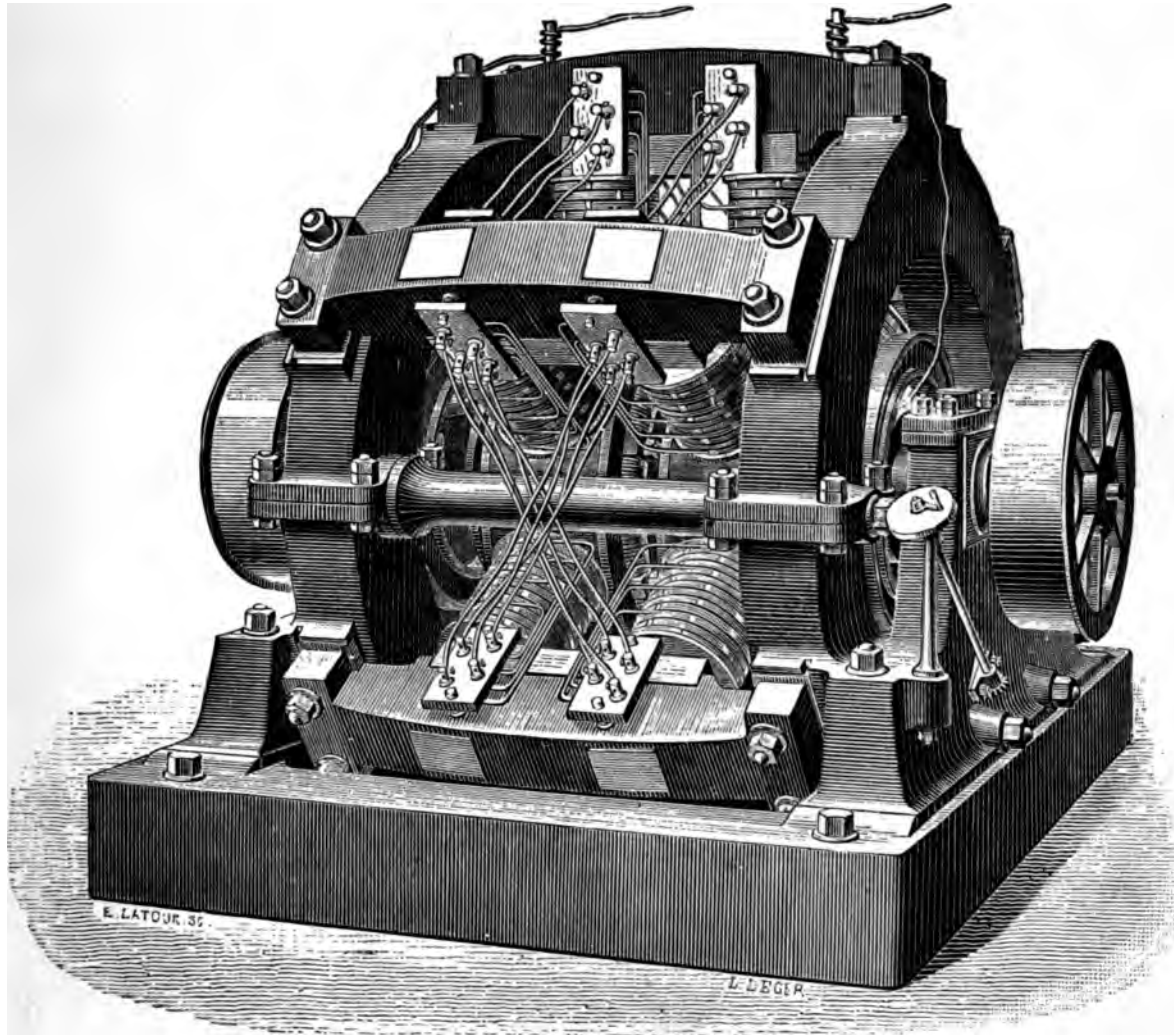


FIG. 47.—DEPREZ GENERATOR AT CREIL, 1885.

The armature is wound in sections after the Pacinotti type, which presents the characteristic that it consists of a series of sections which can be removed and replaced in case of accident. The armature frame consists of a hub with a spider at each end. The sections are separately wound on soft iron cores and are then bolted to and between two opposite spokes on the shaft. Each segment of the armature winding is divided into 21 sections, and the

Total length of wire wound on the ring,	12,012 metres.
Diameter, external,	1,386 mm.
“ internal,	1,070 “
Thickness of wire coil above core,	33 “
“ “ “ “ below “	45 “
Length parallel to axis,	606 “
Weight of wire, including insul.,	552.5 kg.

In a preliminary trial this armature generated an electromotive force of 16 volts per revolution per minute. Each armature has its own

commutator and brushes, the latter being attached to a holder movable by a worm wheel which gears with it.

In a note presented to the French Academy of Sciences, M. Deprez gave the results of experiments undertaken with these machines, and they are quoted below:

FIRST EXPERIMENT.

	Generator.	Receiver.
Speed in rev. per minute,	190	248
Electromotive force, direct or inverse,	5469 volts	4242 volts.
Intensity of current,	7.21 amp.	7.21 amp.
Work in field magnets (in horse power)	9.20	3.75
Electrical work (in horse power) . . .	53.59	41.44
Mechanical work measured with the dynamometer or the brake (horse power),	62.10	35.10

EFFICIENCY.

Electrical,	77 per cent.
Commercial or mechanical,	47.7 "

SECOND EXPERIMENT.

	Generator.	Receiver.
Speed per minute,	170	277
Electromotive force,	5717 volts.	4441 volts.
Intensity of current,	7.20 amp.	7.20 amp.
Work in field magnets,	10.30 H. P.	3.80 H. P.
Electrical work,	55.90 "	43.4 "
Mechanical work (measured with the dynamometer or the brake),	61 "	40 "

EFFICIENCY.

Electrical,	78 per cent.
Commercial or mechanical,	53.4 "

These results which showed that 40 H. P. had been transmitted with a commercial efficiency of about 50 per cent. have been variously criticised. In the first place the generator and motor were placed side by side, the line being in a loop around them. Evidently if leakage occurred on the line it would be the same in effect as if the line were shortened. Again, the power required to magnetize the field magnets, which were independently excited, is not taken into account, so that the mechanical efficiency cannot be taken as the true one.

It will be noted that M. Deprez uses an electromotive force as high as 6,000 volts, which he reached on another occasion, and which of necessity requires an extraordinary degree of insulation, both on the line and in the machines. But in spite of the precautions he had taken he met with a mishap which de-

stroyed one of his machines, and which was caused, no doubt, by the giving way of the insulation.

As it is only by the employment of very high electromotive force that we can approach to a realization of M. Deprez's theory of electric transmission, the question naturally suggests itself: What will be the ultimate result of M. Deprez's experiments, taking into account existing conditions?

In considering this question, Mr. W. J. Johnston in a paper read before the National Electric Light Convention at Baltimore, in February, 1886, reviews the situation in the following forcible remarks. He says:

"That power can be transmitted we all know. Given, then, that M. Deprez succeeds in his attempt, will that alter the present condition of affairs, as regards the *economical* side of the problem? The cost of his installation, and the interest thereon, will far exceed the similar items, including maintenance of a steam plant of equal power, at the place where it is wanted. Yet, paradoxical as it may seem, the great problem to be solved is not the transmission of 100 horse power, but of thousands and tens of thousands. Now, this can only be done in one of two ways; by increasing either the electromotive force or the current. If the latter plan is pursued, an increase in the size of conductor must necessarily follow with its attending cost, and this is feasible, but not at present economical. On the other hand, can the electromotive force be increased much beyond the limit which M. Deprez is now using? Dynamo builders know how perfect the insulation of the armature must be, and how little it requires to burn one out under but slightly abnormal conditions. Those especially who have experimented with the 40, 50 and 60 arc light machines using two or three thousand volts, have possibly, on more than one occasion, witnessed an effect in the armature as if the latter had been struck by lightning. This effect is one entirely different from what would be produced in a machine in which the armature has been actually burned out by a heating of the wires from too great a current. The break resembles that made by a disruptive discharge, an actual spark; and M. Deprez has already experienced one of these mishaps, in spite of the fact that he uses two layers of silk and one of cotton for the insulation. The fact is, a dynamo of large power

which is subjected of necessity to rough influences cannot be made to generate currents of very high electromotive force for a continued service, on account of the impossibility of securing sufficient insulation. The problem bears considerable analogy to that of the steam engine. The use of high pressure steam of, say, 500 or 1,000 pounds to the square inch, would effect great economy, but it is materially impracticable, as the cost of building engines and boilers to withstand these pressures would be out of proportion to the benefits derived, and no working joint could withstand the pressure.

“For the reasons given above it would appear that as regards long-distance *large power* transmissions, substantial improvements are required before it can become a commercial success.”

We have dwelt at length upon the long-distance transmission experiments of M. Deprez,—who indeed stands honorably first and alone in this field thus far,—for the reason that his work presents good ground for study and development. M. Deprez's theory while correct in principle, cannot, unfortunately, be realized in practice to a *commercial* extent, under the conditions prevailing at the present time.

Leaving this part of the subject which is still in the tentative state, and directing our attention to actual successful commercial practice, we find that for moderate distances large powers can be transmitted with ease and economy, as evidenced by the numerous applications detailed in the succeeding chapters.

The time will soon arrive, in fact it is already upon us, when electricity will be distributed for power and light as generally as gas is at present, and it becomes necessary to consider the most economical method of distribution.

The problem of the most economical section of conductor to be employed in a power distribution by electricity is included in this aspect of the question, and is perhaps one of the most important points. In discussing it, Mr. Thomas W. Rae, C. E., assumes for the sake of an example that the amount of power to be circulated in the form of current is 500 horse-power, the length of the circuit 4,000 yards, or 2.27 miles, and the cross-section of the copper conductor 3.25 square inches. The potential of the current is restricted to 120 volts.

The current equivalent of 500 horse power being 373,000 volt-ampères, it follows that the theo-

retical value of the current flowing in the circuit would be 3,108 ampères.

This, however, says Mr. Rae, is subject to correction for the loss involved in the conversion of mechanical work into current; which is due to the frictional and electrical resistances of the generating dynamo. It will be prudent and more in accord with other conditions of the problem—to be stated later—to put this loss at 15 per cent., and consequently there may be considered to be a current of 2,642 ampères flowing in the conductor.

It is evident that the flow of any appreciable current in any practicable conductor must evolve heat. If a uniform temperature of conductor is to be maintained, this development of heat must be got rid of by radiation or conduction; or it becomes cumulative and detrimental, by creating a wasteful resistance in the circuit and, in the case of insulated conductors, sometimes destroying the insulating medium.

The latter class of conductor would seem to offer especial difficulties, and the problem is as yet too new to have invited much investigation or experiment. While it is undoubtedly true that the best dielectrics are, probably without exception, the worst conductors of heat and the rates of their efficiency, in this sense, are practically unknown, it has also been experimentally demonstrated that insulated conductors have even less tendency to augment temperature under the passage of a current than bare wires. This is a deduction from laboratory tests, and must be accepted only within proper limits. The seeming paradox vanishes when one reflects that the worst possible conductor of heat is dry motionless air, and that the larger periphery of the insulated wire radiates the greater quantity of heat in the same time. The result would be reversed if the two types of conductor were exposed to draughts of wind; but the instance is cited to show that the general formulæ are applicable to both classes. Every case, however, may be said to be a special case, and in view of the numberless and unforeseeable influences affecting the temperature of a subterranean conductor two and a quarter miles long, it seems almost final to be calculating the effect of a few degrees due to current resistance. Nevertheless the investigation is of importance.

It is presumable that a conductor buried in homogeneous earth and well below the frost

line would retain about a uniform temperature all the year round, but that temperature would depend upon the nature of the soil.

It would naturally be one thing for clay, another for sand, and another for rock; and none of these could be known except by experiment. In all probability, a conductor of any considerable length would pass through all varieties of soil, across places alternately dry and wet, possibly near steam pipes, and any attempt to assign quantitative temperature to them would be farcical. In such circumstances, the only recourse is to general formulæ, as furnishing—all things considered—as fair an average of the conflicting influences as possible, and one of Clark and Sabine will do as well as any. It is

$$\theta = 0.2405 R C^2 t,$$

in which

θ = units of heat.

R = resistance in ohms.

C = current in ampères.

t = time of flow in seconds.

Since the current in this case is practically continuous, t will disappear, and the factor R must be deduced, Clark and Sabine again furnishing the means with their formula

$$R = \frac{1002.4}{w},$$

w being the weight in pounds of a statute mile of the conductor whose resistance is sought.

In the case in question the weight of a statute mile is 65,261 lbs., and its resistance at 60° Fahr. consequently .01536 ohm; making the resistance of the entire 4,000 yards .035 ohm.

Carrying out the operations indicated by the formula, it will be found that

$$\theta = 58,756;$$

that is to say, the given current will develop in the given conductor so many units of heat.

If it were conceivable that the substance of the conductor was water and weighed just 58,756 pounds, this would mean that its temperature would be raised one degree Fahrenheit. But its material is copper, whose specific heat is .092 or—familarly speaking—which requires but .092 of the quantity of heat that water does to affect its temperature equally; and its weight, as has been seen, is 148,320 pounds.

Adapting the result to these conditions, it will appear that the conductor under consideration will have its temperature raised by the current circulating in it, only 4.17° Fahrenheit, above what it would be if out of circuit.

This increment is so trivial with regard to any harmful influence it might exert upon the insulating medium used with the conductor, that search must be made in other directions for the reason which prescribes its seemingly excessive size.

Good gutta percha will endure a temperature of 120° Fahr. before failing, and india rubber 300° Fahr. So the cause is probably the reduction of current, and consequently of merchantable horse power, resulting from an increase of resistance by augmented temperature.

The resistance of copper increases $\frac{1}{100}$ of one per cent. for each additional degree Fahrenheit of temperature, and in the case of the predicated current and conductor, the resistance of the latter will be enhanced but $\frac{1}{100}$ of one per cent. For the purposes of discussion, the loss of current due to this augmented resistance will be ignored for the present. To estimate the effect of such increase of resistance from a financial standpoint, the subjoined method is convenient.

The 2,642 ampères of current flowing in the conductor are subject to a farther diminution, before they appear in merchantable shape, which occurs in their transformation by the converting dynamos into horse power.

It may be safely taken at 17 per cent.; which amounts to the admission that, of the 500 horse power applied to the generating dynamos, but 70 per cent. may be counted upon as returnable, in the same form, from the converting dynamos. One of the postulates of the problem is that at least this proportion of the applied mechanical power should be recovered after having undergone all its transformations, and the loss has been equally divided—which is probably as fair an allotment as possible—between the two conversions.

There should be, then, 350 horse power available for the production of revenue; but, owing to an idiosyncrasy of electric power, there is very much more. An instant's reflection will satisfy one that where an amount of power is distributed among a number of consumers for intermittent use the chance of every one's desiring to avail of his power at the same instant is

infinitesimal, and experience, as far as it goes, confirms this. The character of the work done may also originate compensating influences to the same end, as when the power-circuit includes elevators which not only consume no power in their descent, but even reinforce the main current with the counter-currents created by their own dynamos revolving under stress of their downward gravitation. It would be difficult to make too much of this characteristic, to which is largely due the wonderful economy inherent in this system of power distribution, and which is so prominent in the case of electric railways as to elicit the statement from the late Sir William Siemens that two trains on the same pair of rails, one ascending and the other descending a grade, influenced each other through the common current as absolutely as if connected by an actual rope.

It is this instantaneous adjustment throughout the entire circuit of the supply of, to the demand for, power that precludes waste or superfluity of it.

It is, therefore, considered perfectly prudent with an ordinary power plant to contract to deliver about double the total capacity of the generator.

In the problem under discussion, the quantity of marketable power was limited to 500 horse power, which represents an annual rental of \$60,000.

It thus appears that every one of the 2,642 ampères of current flowing in the conductor has a market value of \$22.71 per annum.

On the other hand, the specified conductor—at an assumed price of copper, say 15 cents per pound—would cost \$22,248; the annual interest on which, at 6 per cent., would create an annual debit of \$1,335.

Ohm's fundamental law of currents furnishes a useful point of reference at this juncture, viz.:

$$C = \frac{E}{R}$$

in which C = current in ampères,
 R = resistance in ohms,
 E = electromotive force, or potential, in volts.

As the latter factor is fixed at 120 volts, unity may be substituted for it in the formula, viz.:

$$C = \frac{1}{R}$$

which then signifies that the current varies as the reciprocal of, or inversely as, the resistance. Colloquially, it reads: having the same electromotive force, to double the current, halve the resistance, and *vice versa*.

In conductors of similar material and equal length, the relative resistances would be inversely proportional to their cross-sections—or to their weights—and the final deduction is that currents of uniform potential moving in conductors of the same material and of equal length vary as the weight of the conductors.

A convenient unit of comparison is the annual market value of the ampère which, as has been shown, is \$22.71. As the number of salable ampères in the case in point is a function of the weight of the conductor, the annual interest upon which *per pound* is \$.009, viz.:

$$\frac{1,335}{148,320} = .009,$$

it follows that it would require the annual interest upon 2,523 pounds of copper, viz.:

$$\frac{22.71}{.009} = 2,523,$$

to equal the annual value of one ampère.

Supposing the conductor to be reduced in weight by this amount and applying the rule deduced for this especial case—of the current varying as the weight—it appears that such a reduction would diminish the current some 45 ampères, viz.:

$$\begin{array}{r} 148,320 \\ 2,523 \\ \hline 148,320 : 145,797 :: 2,642 : 2,597 \\ 2,642 - 2,597 = 45, \end{array}$$

whose annual value is \$1,022.

It thus becomes evident that the diminution of weight would entail vastly greater loss of revenue than the annual saving achieved thereby. Reducing the two opposing quantities to a common unit will give useful constants for the case under discussion, viz.:

Annual interest at 6 per cent. on 1 lb. copper = \$.009.

Annual revenue from 1 lb. copper = \$0.40.

Weight of copper per ampère = 56 lbs.

From which it appears that until the price of copper rises forty-five times above its present

figure, or the value of the ampère falls the same number of times below that assigned to it in the comparison, or a change occurs in both, producing a similar mutual relation, any reduction of weight in the conductor—all other factors remaining constant—would be a source of loss rather than of profit. Since it seems uncontestedly proven that for the stated case and specified conditions any diminution of the conductor would be prejudicial, it becomes of interest to know if the weight might be profitably increased.

It will be remembered to have been shown above that the given current raised the temperature of the conductor 4.17° Fahr., which increased its resistance .86 of one per cent.

Since current varies inversely as resistance, viz.,

$$100.86 : 100 :: 2642 : 2619$$

$$2642 - 2619 = 23,$$

it appears that this trifling increment reduces the flow by 23 ampères whose annual value is \$522.33. In the given conductor and under the prescribed conditions, each ampère requires 56 pounds of copper, and the addition of 1,288 pounds (56 × 23 = 1,288), the interest on whose cost is but \$11.59, would make good this very considerable annual loss. Increasing the conductor by this amount of copper would enlarge its cross-section from 3.25 to 3.30 square inches—a barely appreciable area.

It is evident that the method employed is only approximative, and may be continued to any desired degree of precision. There is no pretence of close accuracy, and it is even less than it might easily be, on account of ignoring fractional quantities and the ordinary small errors in the deduced factors made use of. The idea has been rather to suggest a method of dealing with such questions than to furnish absolute results.

Sir William Thomson has given a formula for computing the most economical section of conductor, which may in some cases be used with advantage, although it is not adapted to all cases; but here again it must be left to the engineer to decide when to use or how to modify the formula.

The resistance of any circuit may be expressed by the formula,

$$R = \frac{l}{s} r,$$

l representing the length of the conductor, s its cross-section, and r being the specific resistance of the metal used—that is, the resistance of a bar 1 metre long, and having a cross-section 1 square millimetre.

The loss of energy through heat, expressed in metre-kilogramme-second units is

$$H J = \frac{C^2 R}{9.81} = \frac{C^2 l r}{s 9.81},$$

or for unit length (1 metre),

$$H J = \frac{C^2 r}{s 9.81}.$$

Now there are 31.5×10^6 seconds a year, but the current is only used part of this time—that is, for $31.5 \times 10^6 \times p$ seconds only (where p represents a fraction greater than zero and less than 1).

The amount of energy, therefore, lost in one year is:

$$A = \frac{31.5 \times 10^6 \times p C^2 r}{9.81 s}.$$

Let P stand for the cost of one horse power per year; then the cost of one unit of work (M. K. S. system) will be

$$\frac{P}{31.5 \times 10^6 \times 75'}$$

and the cost of A units—that is, of the amount of energy lost in a conductor 1 m. long and with s square mm. cross-section—will be

$$L = \frac{P p C^2 r}{9.81 \times 75 \times s}.$$

Now, if interest on investment capital be taken at c per cent. a year, and the cost of one cubic metre of the material be v , then the cost of a conductor one metre in length and s square mm. cross-section will be

$$L^1 = s v 10^{-6} c.$$

The total is:

$$L + L^1 = \frac{P p C^2 r}{9.81 \times 75 \times s} + v 10^{-6} c s.$$

This will be a minimum if L is equal to L^1 —that is,

$$\frac{P p C^2 r}{9.81 \times 75 \times s} = v 10^{-6} c s;$$

from which equation we get

$$s = \sqrt{\frac{P p C^2 r}{9.81 \times 75 \times 10^{-6} \times v c}} = C \sqrt{\frac{P p r 10^6}{9.81 \times 75 \times v c}}$$

or if $c = 5$,

$$s = 162.56 C \sqrt{\frac{P r p}{v}}.$$

CHAPTER V.

THE MODERN ELECTRIC RAILWAY AND TRAMWAY IN EUROPE.

SOME experiments were tried in 1867, at Berlin, in electric railways, by Dr. Werner Siemens, but the work was abandoned because the armature of the Siemens machine then used became heated too quickly and too greatly to be of practical service. Under conditions of more promise, the experiments were resumed by Siemens & Halske in 1879, and carried to a successful issue.

The first step which Messrs. Siemens took towards a practical demonstration consisted in the building of a short line of about 500 metres length at the Berlin Exhibition of 1879. In this they employed their well-known type of machines as generators and motors, of which the illustration shows one connected to a Dolgrouki rotary engine, Fig. 48, and a central rail led the current to the machine, the outer rails acting as a return circuit. Prompted by the success with this venture, which was the first of its kind, similar attempts were made in Brussels, Düsseldorf, and Frankfort, for exhibition purposes, with a like result. The first permanent undertaking executed on the Siemens system, however, did not take place until two years later, when, on the 12th of May, 1881, the line between Lichterfelde and the Central Cadetten Anstalt, near Berlin, was opened to the public. This installation differed somewhat in detail from the first attempts in the manner in which the current was led; for whereas in the latter a third central rail was used, the former employed only the two existing rails, one as a lead and the other as a return circuit.

Since this road was put in operation Messrs. Siemens & Halske have built numerous others, and we need only to mention those of the Paris Exhibition, at Vienna, at the Zankeroda mines in Saxony, at Offenbach, near Frankfort-on-the-Main, and the use of the system on the Portrush Railway in Ireland, in order to show the enterprise of a firm which American electricians might well take as an example.

The various methods which the Siemens have employed for conducting the current to and from the motor deserve some attention, as they have by no means restricted themselves to the rails as conductors, but have devised various methods for the purpose. As stated above, their first road employed a central rail, while the second used the main rails only. In order, however, to avoid the danger of giving electric shocks to persons and animals coming in contact with these unprotected rails, and also to avoid the loss due to leakage between the rails in wet weather, recourse has been taken to overhead conductors which lead the current without the objections just named. The first and most natural way out of this difficulty was to string two wires overhead upon which small trolleys travelled. These latter were connected to the locomotive by wires which pulled them along, and thus a constant circuit between motor and generator was maintained. This method, though simple, was found not to work well in practice on account of the vibration and the varying sag in the wire, and another was consequently devised, which was first tried at the Paris Exhibition of 1881, and gave satisfactory results. On this occasion the overhead conductors consisted of brass tubes, slit longitudinally and laid along small stringers of wood, so that the slit was turned downward. Within the tube there was placed a short metal cylinder, at the ends of which there projected two lugs, which passed through the slit in the tube and were connected to a small framework carrying a wheel. The latter was pressed against the lower side of the tube by springs, and thus a good contact was obtained when the wire from the locomotive was attached to the device.

At the Zankeroda mines still another method is employed, well suited to the locality. This consists in suspending two \perp beams with their flanges facing downwards. The lower flanges

thus present a good means for the conveyance of a trolley, and the latter being provided with a brush, takes off the current, with very little loss of power. It will be seen that for mines this disposition of the conductors is a very happy one. The rough usage to which the rails are subjected, together with the frequent presence of water, makes the employment of the former as conductors impracticable; but the \perp rails suspended close to the roof, and attached to hard rubber insulators, leave little to be desired in the matter of efficiency. The motor at

application of electricity as the chief motive power for propelling the tram-car; and 5th. The use of water-power as the actual source from which the motive power is derived. The line is a continuous series of long inclines. Gradients one in forty-five and one in forty are frequent for upward of a mile in length, while steeper gradients of one in thirty exist for shorter distances, the worst gradient being one in twenty-five, the total rise from the depot at Portrush to the summit being 203 feet. The system finally adopted of utilizing electricity

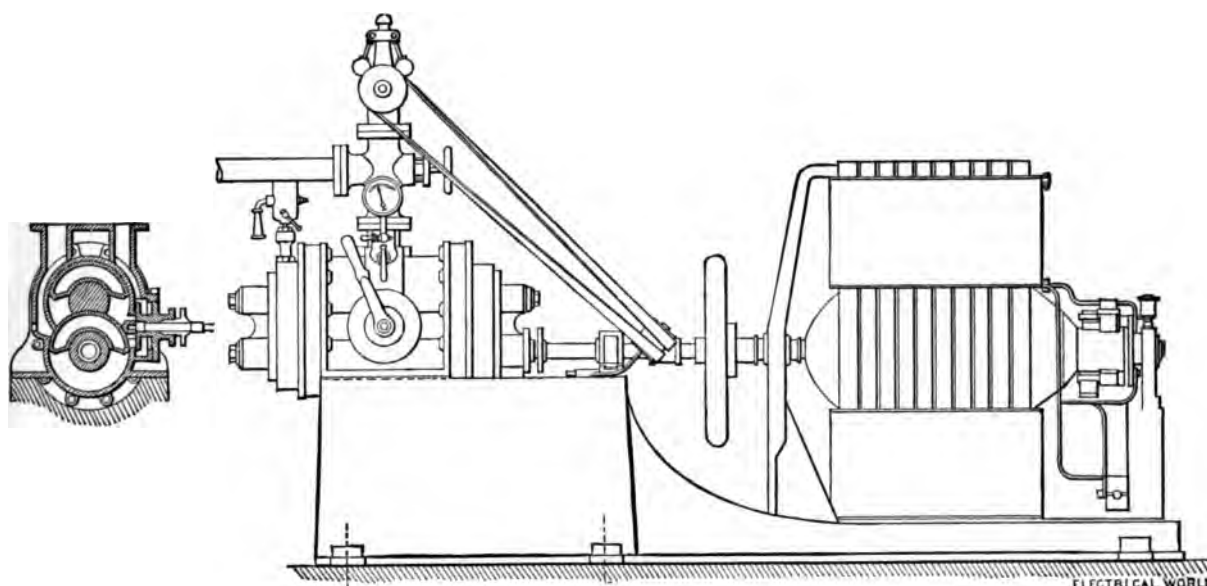


FIG. 48.—SIEMENS' DYNAMO WITH DOLGOROUKI ENGINE.

these mines weighs about $1\frac{1}{2}$ ton and is capable of hauling a load of eight tons at the rate of seven or eight miles an hour.

The main features of the Portrush road were described by Dr. Anthony Traill, LL. D., chairman of the Portrush Electric Railway, at the Montreal meeting of the British Association for the Advancement of Science, in 1884. This line, he said, was specially constructed with a view to the application of electricity as a motive power. The chief distinctive features by which it differs from tramways, as usually constructed, are: 1st. The gauge, which is three feet; 2d. The position of the tramway in respect to the side of the road, viz., it being placed alongside of the road, and not in a central position, and being raised slightly above the surface of the road; 3d. The form of the rail, a flange being substituted for a grooved rail; 4th. The motive power, the

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as the motive power differs from the system used on the Lichterfelde, the Charlottenburg and the Paris electric tramways, where overhead electric conductors or storage batteries were used. The track being laid along the side of the road, a third rail or rigid electric conductor is placed along the toe of the fence or ball, consisting of from twenty to thirty foot lengths of T irons, weighing nineteen pounds to the yard, supported on short wooden posts with insulating caps of "insulite," the top surface of the conducting rail being three inches wide and eighteen inches above the level of the tramway rails. The ordinary track rails constitute the "return," completing the circuit. The electricity is now generated by water power on the River Bush, situated at a distance of 1,600 yards from the nearest point of the tramway, and five and a half miles from Port-

rush, Fig. 49. A fall of twenty-six feet head of water is used to drive two of Alcott's turbines, each capable of working up to fifty-two horse power. These drive on a single shaft, which communicates by belting with a generating Siemens dynamo, giving a maximum current of 100 ampères with 250 volts E. M. F. Each electric car is fitted with a starting handle at each end, and with powerful brakes, and is capable of drawing a second car behind it, with a total complement of 44 passengers comfortably seated. The daily running of the electric cars commenced on November 5, 1883, from which date till July, 1884, upward of 13,000 electrical train miles had been run. The working expenses of the electrical train mile are five cents a mile as compared with eleven and twelve cents per steam engine train mile, and the average cost of twenty cents to twenty-four cents per mile, when horse power is used. The line continues down to the present time in most successful operation. An extension of six miles is in contemplation, and a 12 per cent. dividend is paid. Speaking before the Inventors' Institute in 1885, Mr. Traill, the engineer of the road, stated that 30,000 train miles had then been run, and that 100,000 passengers had been carried. He also said that after repeated trials the management had found an efficient method of making contact between train and conductor. This consists in the use of a steel spring in the shape of a carriage spring; two of these, concave, are fastened at the top and rub along the bottom. The cost and the wear are nominal. The total resistance of the line from the generator and back is 1.9 ohms. Where the rails are crossed by roads, an insulated cable is laid under ground and it connects the two ends of the severed rails, so that the latter, though elevated along the line, do not prevent the crossing of vehicles. As there are two sets of brushes attached to the motor, one in front and the other in the rear, it follows that at short crossings the front brush makes contact before the rear one has left the rail, and thus an uninterrupted current is maintained. Where the crossing is greater than the length of the car, the momentum of the latter carries it over to the opposite end, and in this manner makes connection again.

The Siemens line at Lichterfelde, a suburb at Berlin, has been in operation since May, 1881. The rails rest on insulated sleepers. One rail is

positive and the other negative, or return. The gauge is three feet three inches. Each car is driven by its own motor, and has a carrying capacity of 26 passengers. The movement of the motor armature is transmitted to the car wheels by means of a belt working on cylinders outside the wheels. The cars are provided with brakes, which may be put on at either end, so that they will run in either direction without being turned around on the track. Yet another Siemens road was put in operation between Mödling and Brühl, near Vienna, in 1884, for a distance of over two miles. This line has since been in course of extension to Hinterbrühl, making it about a third longer.

The cities of Frankfort and Offenbach are connected by a Siemens electric railway, 6,665 metres (about 4 1-8 miles) long, of 39 inches gauge. It leads from the old "Römerbrücke" Frankfort, through Sachsenhausen, Oberrad, and through the entire town of Offenbach. The trains run over the entire route in about 25 minutes. Two steam engines, of 125 horse power each, drive four dynamo-electric machines and the current is conducted through suitable cables and conductors over the entire line. A switch is provided, regulating, governing, and directing the currents, as may be necessary. The conductors consist of tubes slotted along their entire length at the bottom, and insulated on poles in about the same manner as telegraph wires are arranged. In these tubes a small cylinder slides or runs, from which a conductor extends down to the car and to the dynamo in the same in the usual manner.

We have entered into this detailed description of the methods employed in the Siemens system, because the points involved are of great importance, and may often determine the practical success of similar undertakings. As regards a choice of conductors for electric railways, it is obvious that no definite rule can be laid down, as the method employed must be governed entirely by the exigencies of the case. It is thus seen that at Lichterfelde, which is but sparsely populated and has but little traffic, the rails alone have been used as conductors. In Paris the case was entirely changed, for there the rails lay flush with the street, the city authorities not permitting a raised rail to interfere with the continuity of the pavement. This prevented good insulation, and, in ad-

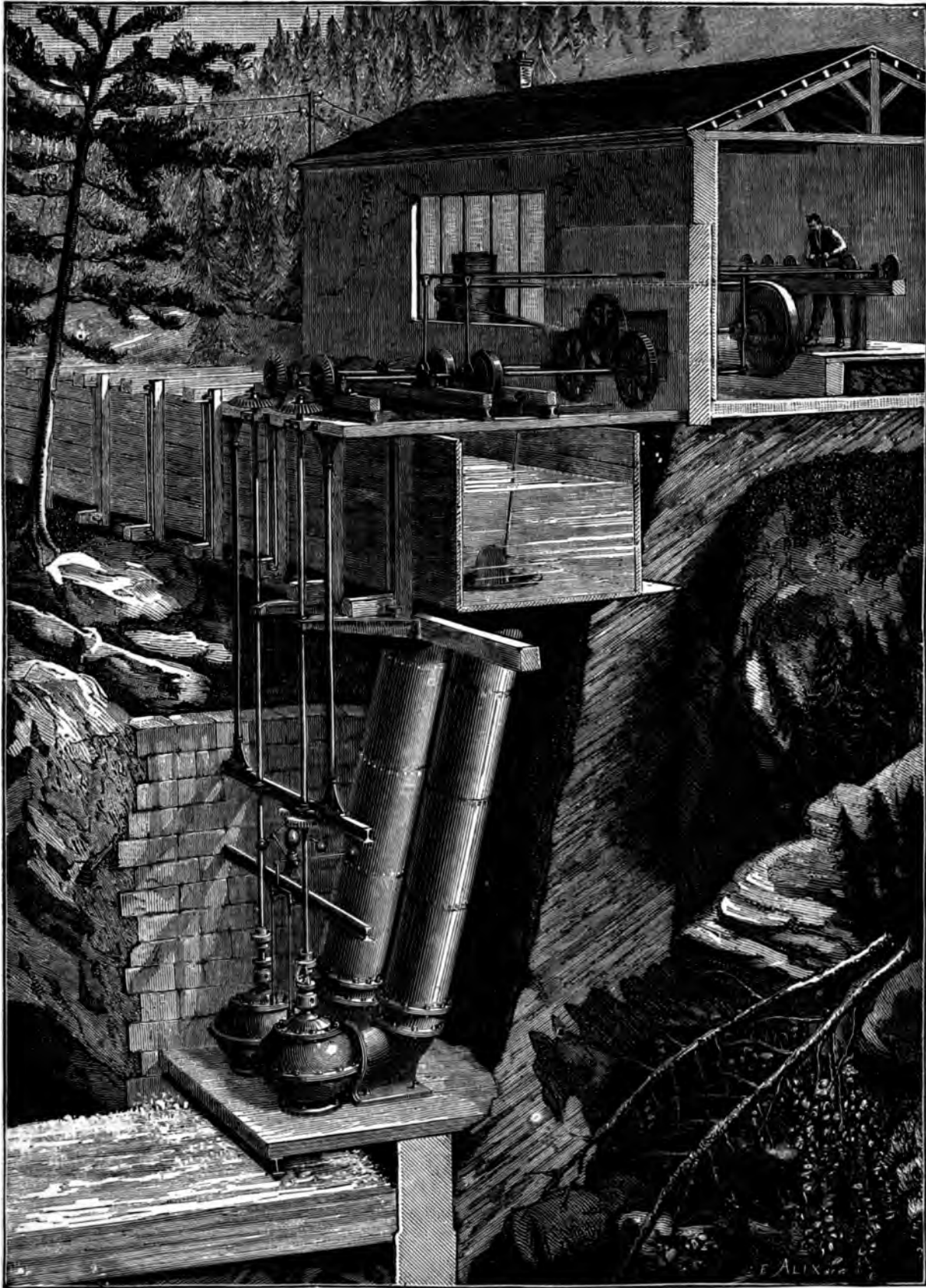


FIG. 49.—THE WATER POWER OF THE PORTRUSH RAILROAD.

dition, the sunken rail permitted the accumulation of dirt and other matter which would have prevented the wheels from making good contact. All this being foreseen, it became necessary to provide overhead conductors, taking the form described above. At the Zanker-

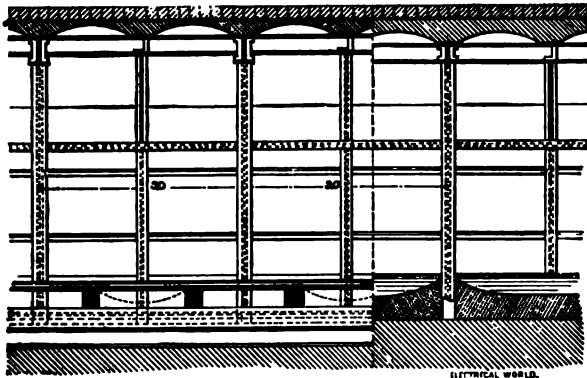


FIG. 50.—TUNNEL FOR VIENNA ELECTRIC RAILWAY.—LONGITUDINAL SECTION.

oda mines the form adopted seems eminently practical, and will no doubt be copied in future installations. The exemplifications might be continued, but those enumerated will suffice to show what has been done in that direction, and to point the way to a selection of the best method to be applied to a given case.

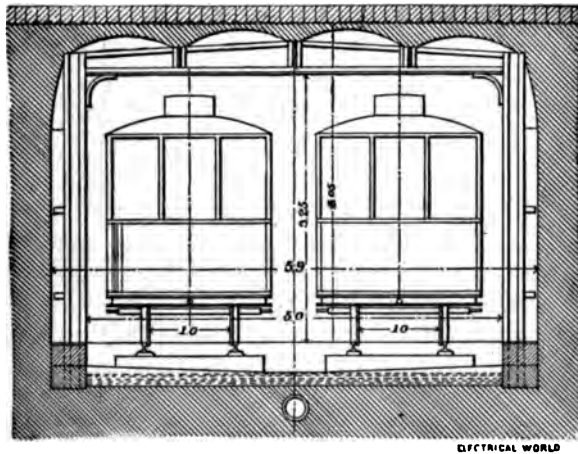


FIG. 51.—TUNNEL FOR VIENNA ELECTRIC RAILWAY.—TRANSVERSE SECTION.

We now come to the consideration of the proposed Vienna system of electric railways which has been elaborated by Siemens & Halske, and which, if carried out, will undoubtedly place that city in the front rank as regards transportation facilities within city limits.

The projectors start out with the proposition that no such railway can be run on the surface of the street, for the reason that contact with the rails would be unavoidable, especially at car crossings, and principally on account of the limited speed which surface railways are obliged to run at. Where quick transit is desirable, therefore, the solution must be sought either in an underground or an elevated system, or in

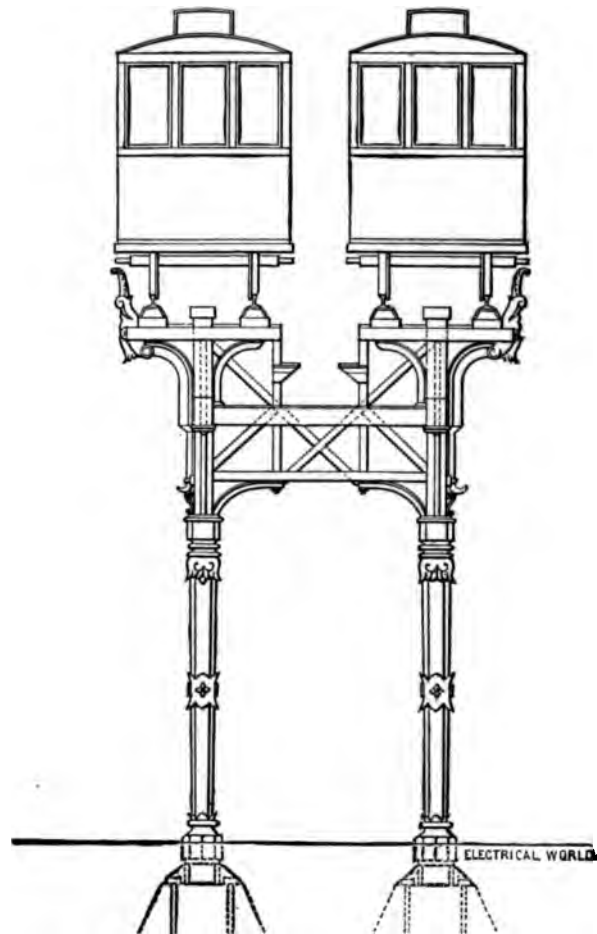


FIG. 52.—ELEVATED STRUCTURE FOR VIENNA RAILWAY.

a combination of both, depending upon the nature of the surface. The last named plan is the one proposed for Vienna, where the rise and fall of the ground would present too heavy grades for either one of the first two systems mentioned. It is therefore proposed to build a road in which tunnels shall alternate with elevated structures, and the manner of building both of these is shown, as they give a good idea of the requirements of the case; Figs. 50, 51, and 52.

As regards the construction of the tunnel, of which we give two views, it will be seen to have a flat roof instead of an arched one. This is necessary, because the latter construction would require a greater height of tunnel, and in addition an increased width. One object in making the tunnel as low as possible is to minimize the grades in passing from tunnel to viaduct, and by making the tunnel as narrow as possible, plenty of room, even in the narrowest

Respecting the viaduct or elevated portion of the road, an essential condition requires it to be as simple as possible. It must be open so as not to obstruct the light, and this requires the parts to be small and simple. Hence the illustration shows both rails supported by only one main girder bracing between them. It is asserted also that this method of construction will diminish the noise of passing trains—a boon that only the dwellers along the lines of

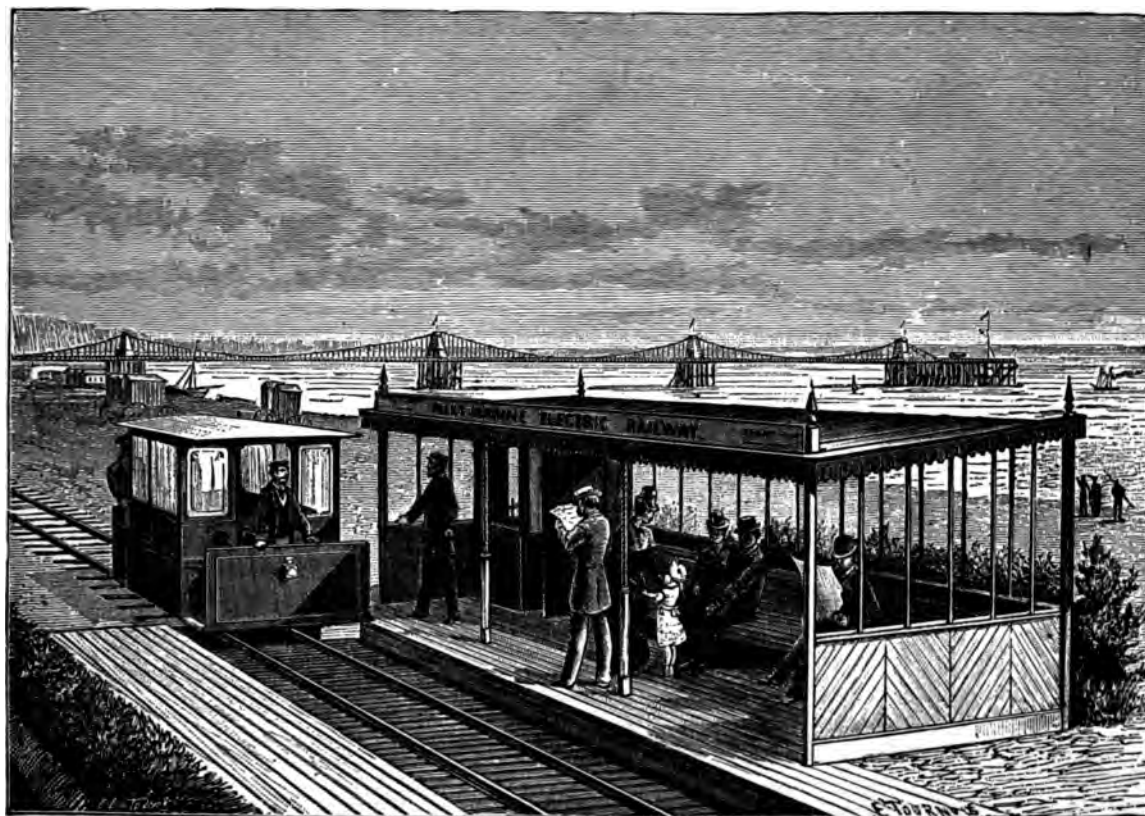


FIG. 53.—THE BRIGHTON, ENGLAND, ELECTRIC RAILWAY.

streets, remains on both sides, for the placing of sewer and other pipes, without interfering with the foundations of houses. Ventilation of the tunnel will be effected by means of perforated plates inserted in the roof and arranged so as to catch any matter that might fall through the holes. They would so act that when a train approached one of them it would force out the foul air through the openings, and as it receded it would draw in a supply of fresh air; plates thus placed at proper intervals would maintain good ventilation. It goes without saying that the cars are to be lighted by electricity.

the rattling and vibrating New York elevated roads can appreciate in its full extent. The course that these lines will take in Vienna demands attention. Although it is not proposed to build the entire road at once, the plan has been so worked out that, when complete, the system will present a network giving access to all parts of the city, from any starting point, in the shortest time. We can best explain the course of the road by asking our readers to imagine a circle drawn: around this inner circle there are drawn others in such a manner that each one shall touch its neighbor and also form part of the circumference of the

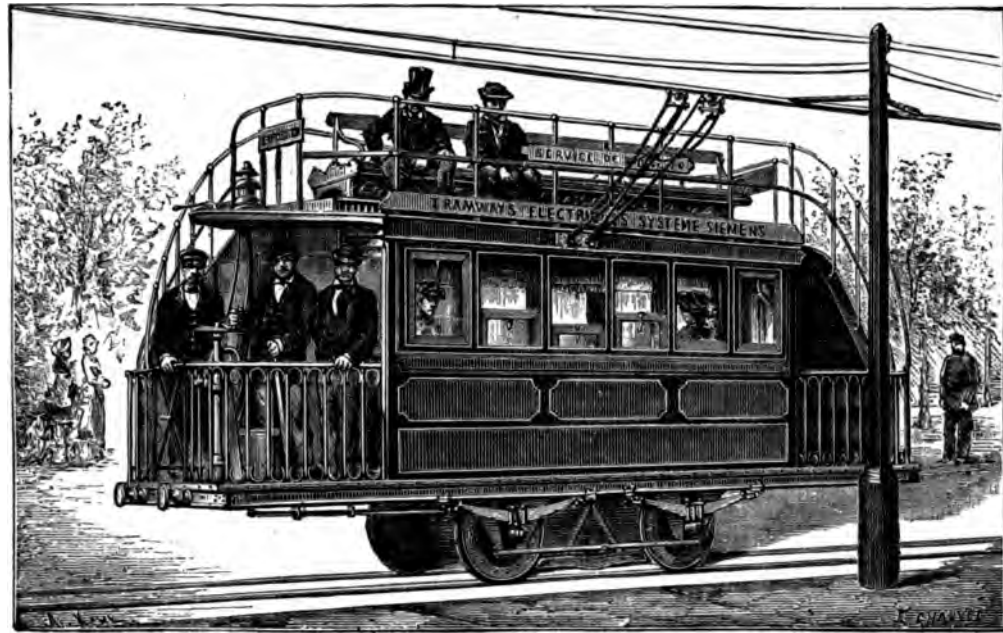


FIG. 54.—THE PARIS ELECTRIC STREET RAILWAY OF 1881.

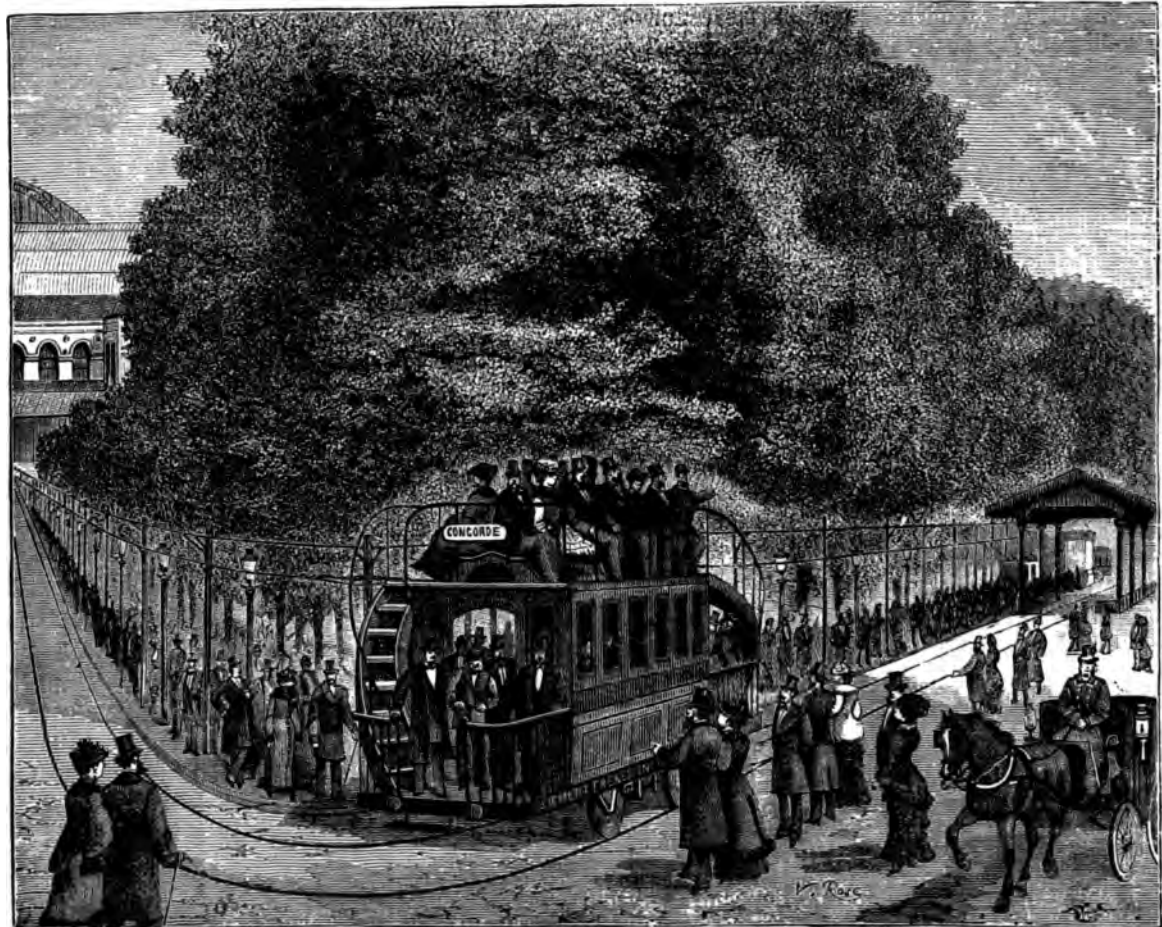


FIG. 55.—THE PARIS ELECTRIC STREET RAILWAY OF 1881.

inner circle. It will thus be seen that any part of the city can be reached, no matter in what direction, in the shortest time consistent with such a comprehensive plan. It will of course be understood that the lines proposed do not take the shape of true circles.

An English railway that has been a notable success, though on a small scale, is that operated during the past two years at Brighton, the well-known watering place, by Mr. Magnus Volk. The line, Fig. 53, is rather under a mile in length, and includes some heavy gradients on sharp curves, the gauge being 2.9. The speed is limited to eight miles an hour, but a speed of over twenty-five miles has been obtained. The current is transmitted along the rails, which are fastened to wooden sleepers resting on the shingle, no special insulation being used. Each car seats thirty passengers, and the motor can draw another if necessary.

The plant comprises two cars fitted with motors; one eight horse power gas engine, one twelve horse power gas engine, one Siemens D₂ series dynamo, one Siemens D₂ compound dynamo.

The working expenses for one year are given as follows (average for two years): Electrical machinery — new commutators and brushes, \$48.12; gas engines—refacing slides, etc., \$31.17; oil and waste (that used for axles included), \$48.30; gas (including that used to light premises, price 78 cents per 1,000 cubic feet), \$547.93; attendant, 52 weeks, at \$4.32, \$224.64; total, \$900.16. The gross earnings per car mile are 38½ cents; the gross expenses (all renewals being paid out of revenue), 22½ cents; car mileage per annum, 23,475; cost of haulage per car mile, 3.84 cents, barely 4 cents; this includes the engine attendant.

Only one car is running, except on bank holidays, etc., on which occasion nearly all the power of the 12 horse engine is used. The repairs to the electrical machinery only amount to 5 per cent. per annum, and to the gas engine only about 2½ per cent. The only repairs to the electrical machinery of the two cars—the work having been nearly equally divided, each car having run about 25,000 miles—have been one new commutator and one spindle bush relined with soft metal; that, therefore, represents the wear and tear for nearly 50,000 miles running. The extra cost of running two cars is very slight, only about two-thirds more gas being

required, and the other expenses being scarcely affected.

Figs. 54 and 55 illustrate the electric car used during the Paris Electrical Exposition of 1881, and referred to above. This car carried 84,000 persons. The motor was placed under the car body. The second view shows the car turning the sharp curve from the Champs Élysées to the Palais de l'Industrie, where the exposition was held. The first view shows the car from the other side, so as to make plain the method of taking the current from the conductors placed on poles and parallel with the line of track.

The Siemens road that was in operation at the Vienna Electrical Exposition in 1883, is illustrated in Fig. 56. The track was 1528 metres in length. A Siemens motor was placed under the floor of each of the two end cars, and the current was furnished by two Siemens dynamos coupled, so that the current from each armature excited the other's field magnets. One rail was connected with the positive binding post common to both machines, and the other rail with the negative post alike belonging to each. An electromotive force of 150 volts was maintained.

The road most worthy of notice in England after those at Portrush and Brighton is that of Mr. Holroyd Smith, at Blackpool. On the Blackpool tramway every means has been taken to reduce the objections of electric lines in cities to a minimum, as will be seen by our illustration, Fig. 59, which represents a part section of the road-way in perspective. The entire electrical part of the road is below the surface of the street, and the rails are not used as a conductor. The latter consists of two copper tubes, *C*, of elliptical shape, and having a wide slot for facility of attachment to iron studs, *S*, which are supported in porcelain insulators, *I*. The latter are themselves attached to blocks of creosoted wood in the sides of the channel. The tubes are fixed to the studs by the simple device of a wooden pin wedge, *W*, and they are coupled to each other by two metallic wedges, as shown in our illustration, Fig. 58.

The car which is employed is shown in plan and in longitudinal section, in Figs. 57 and 60, which are so clear that no extended description appears to be necessary.

At each end of the car there is a switch-box with resistance coils placed under the plat-

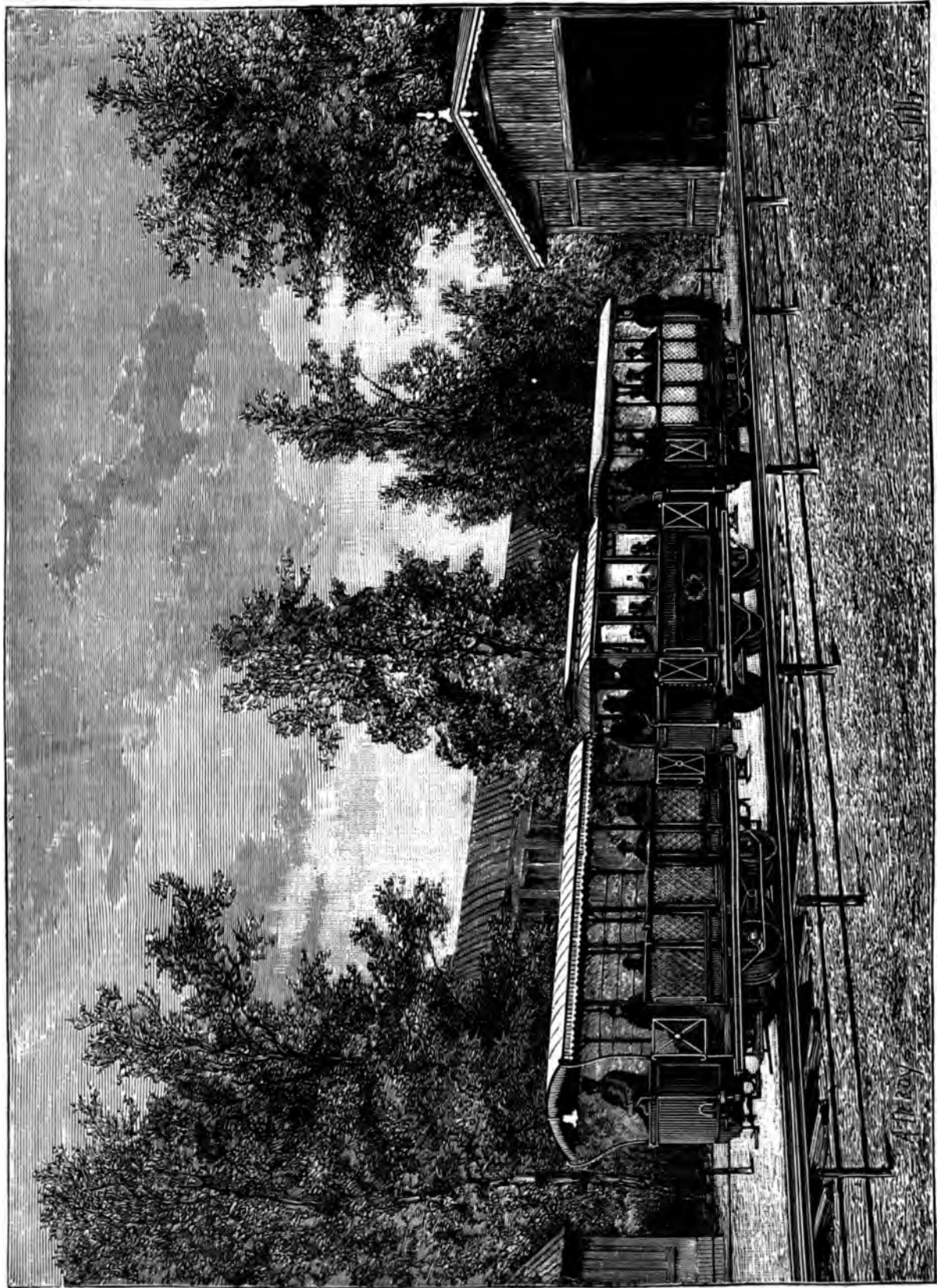


FIG. 56.—THE ELECTRIC RAILWAY AT THE VIENNA ELECTRICAL EXPOSITION OF 1883.

forms, by which means the strength of the current and speed of the car can be regulated. To reverse the direction in which the car is traveling, the direction of the current through the armature is reversed, the field magnets, which are shunt-wound, remaining always magnetized in the same sense. With this arrangement there is no need to alter the position of the brushes, which in this case consist of two parallel sets of plates placed tangentially to the commutator, and pressed on it by spiral springs. There is only one handle to the two switch-boxes, and that being in possession of the driver, the possibility of accidents caused by interference of others with the electrical connections is precluded. The current is generated by four-pole Elwell-Parker dynamos, Fig. 61, and the motors are also manufactured by that firm. The line is in continuous and highly successful operation. It is about two miles in length.

The dynamos are three in number, two of extra large size for generating the electricity for driving the cars, and the third a much smaller one, for exciting the "generators." These machines were manufactured specially for this work by Elwell-Parker, Limited, of Wolverhampton. The "exciter," Fig. 62, is of their usual type. The length, including pulley, is 3 ft. 3 in.; width, 2 ft.; and height, 2 ft.; its total weight is about 10 cwt. The diameter of the armature is 10 in., with a length of 13 in. The resistance of the field magnets is 60 ohms, and the electromotive force is 150 volts, with a current of 16 ampères. The brushes and commutator are of the usual form. The generators, Fig. 61, are among the largest of this form of dynamo yet constructed, and, as may be seen, differ materially from the Elwell-Parker type; each dynamo consists of two field magnets, with a commutator carrying four sets of brushes in pairs. These brushes are fitted with springs, which are easily adjustable, so that they can be kept just clear of the commutator or instantly dropped into contact. These machines are 7 ft. 3 in. long over all, 5 ft. 8 in. wide, and 2 ft. high, weighing altogether about four tons; they are provided with slides and adjusting screws, are run at a speed of about 650 revolutions, and produce an electromotive force of from 200 to 300 volts (according to speed), and a current of about 180 ampères; the resistance of the field magnets is about 30 ohms, and

that of the armature .004 ohm; the armature is 3 ft. long by 16 in. diameter, and from the illustration it can be seen that it is well ventilated. The machine is massive in construction, and well finished, and it is said to run with the greatest freedom from heating in all parts, a very desirable feature. The dynamo or motor in the cars is run at a speed of 800 revolutions per minute, with an electromotive force of 200 to 250 volts, and a current of about 20 ampères; the resistance of the field circuit is 14 ohms, and that of the armature .074 ohm. There is one point of interest to which it is necessary to call attention, and that is the position of the brushes with regard to the commutator. The cars, which are 13 ft. 6 in. long by 6 ft. 6 in. wide, are arranged so that their position remains unchanged on the line, and consequently it becomes necessary to reverse the "motor" to drive the car either forward or backward. If brushes were fixed in the ordinary way they would be right for proceeding in the one direction, but reverse motion would at once double back the copper wires of the brush. The brushes are therefore fixed as near as possible opposite the centre of the commutator, and are therefore in the same plane and exactly at right angles to a line drawn perpendicularly through the commutator. Their *ends* press directly against the bars of the commutator, and they are fixed relatively to each other, and so balanced that any alteration in the position of the one produces a corresponding alteration in the other, so that the brushes are kept exactly opposite each other. The switch arrangement of the cars consists of two portions, one a switch for reversing the direction of the current, and the other for starting the car. The former controls the direction of the motion, the latter its starting and stopping, and also its rate of progress.

These switches are contained in wooden pedestals placed under the steps leading to the roof, one at each end. The starting switch consists of a projecting handle, which is moved forwards or backwards; this handle is screwed on to the end of the inside switch, which, moving over certain brass contact pieces, brings into the circuit between the charged conductor and the motor certain resistances which have the effect of diminishing the speed of the armature of the motor. It will be seen, therefore, that a slight alteration of the handle, altering

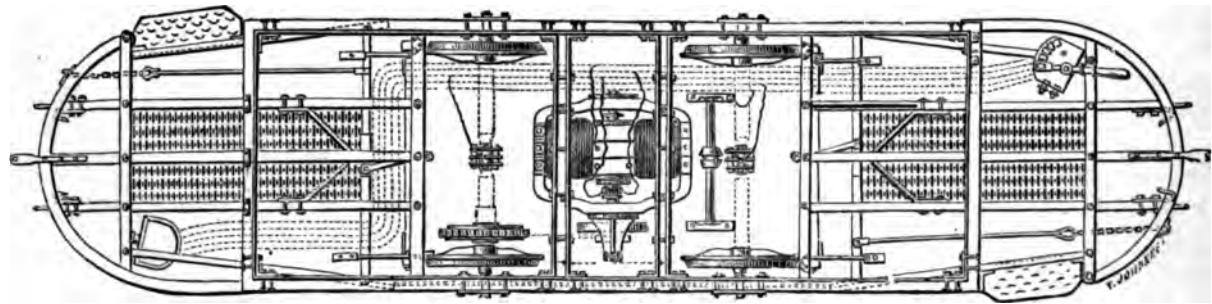


FIG. 57.—PLAN OF CAR

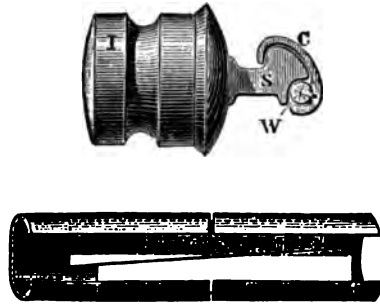


FIG. 58.—DETAILS OF CONDUCTOR IN CONDUIT.

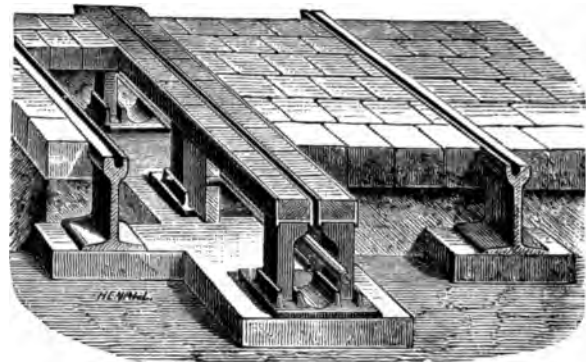


FIG. 59.—SECTION OF ROADWAY.

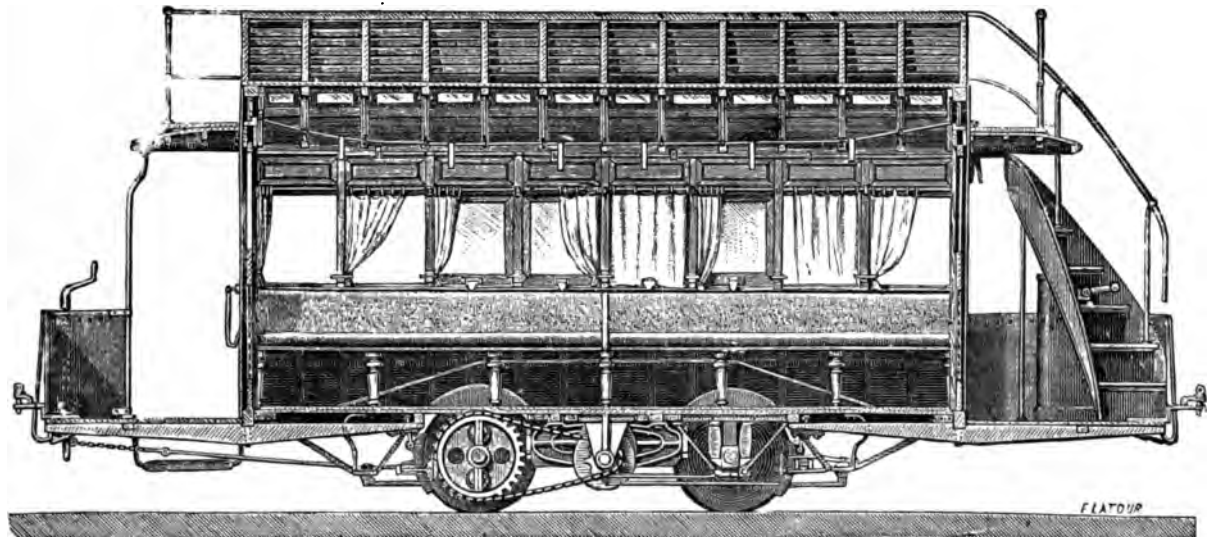


FIG. 60.—BLACKPOOL, ENGLAND, ELECTRIC STREET CAR.

the resistance in circuit, produces the required effect in increasing or decreasing the speed of the motor. These resistances are made of carbon rods (similar to those used in an electric arc lamp) firmly attached to brass connecting pieces.

The Besspool electric tramway was inspected and passed without alteration by the English government authorities in 1885, and has lately been accepted from the contractors as satisfactory. It has been constructed to form a link between the mills and granite quarries of the Bessbrook Spinning Company and the railway at Newry, the distance between the two places

The flangeless wheels run upon these outside rails. The maximum gross load of a train is twenty-six tons, consisting of six wagons, which carry about two tons each, and the electric locomotive, weighing eight tons, which also forms the passenger carriage, and is capable of accommodating thirty-four passengers. This load can be drawn up inclines averaging one in eighty-five at a speed of seven miles an hour, and up the steepest incline of one in fifty at a speed of six miles an hour. The train can be started at any point of the line without difficulty. The motive power is electricity furnished by dynamos situated about two miles

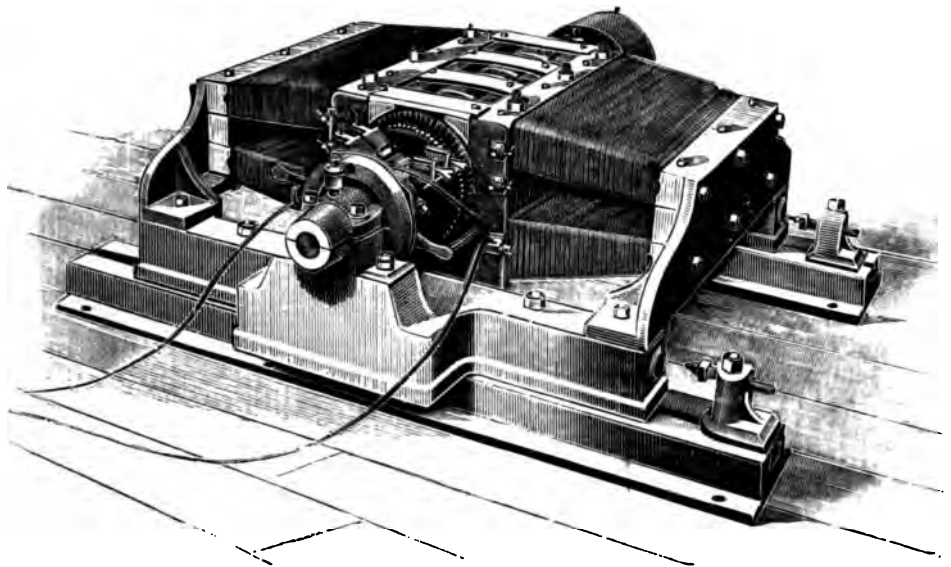


FIG. 61.—GENERATOR AT BLACKPOOL.

being three miles, and the annual traffic, which has hitherto been carried in carts, being about 28,000 tons. The tramway differs from others in that the vehicles are equally well adapted to run on the rails and the ordinary roads, this facility being required by the difficulty which was found in connecting the line to the railway at one end, and to every department of the works at the other. They are carried on four wheels $2\frac{1}{2}$ inches wide and without flanges; the first pair are on a bogie, which can be fixed to form a rigid wheel base, or have shafts fitted to it, and allowed to swivel after the manner of the leading axle of a coach. These wagons carry two tons each, and can be drawn by a horse up moderate grades. On the outside of the ordinary tramway rail, second rails have been laid, to which the ordinary rails act as guards.

from Newry, at Millvale, and driven by a turbine, constructed capable of developing sixty-five horse power. The conductor consists of an inverted steel channel carried on insulators, and fixed midway between the ordinary rails. Both the generators and motors are of the Edison-Hopkinson type, constructed by Messrs. Mather & Platt, and are capable of developing twenty-five horse power. The locomotive is geared to run at a maximum speed of fifteen miles per hour, and this speed is easily attained when there are no trucks attached. The cars are 35 feet long over all, and are carried on bogies at each end, so that they pass readily around curves of 55 feet radius.

M. Lartigue, the well-known French engineer, has applied electricity to the traction of the panniers or cars of his single-rail tramway.

This tramway is employed in Algeria for transporting esparto grass from the interior by the traction of camels. It was an easy step from animal to electric traction, and M. Lartigue has successfully taken it. At a recent Agricultural Exhibition in the Palais de l'Industrie of Paris, a line was shown on which five iron panniers, or double cars in the form of seats, were drawn by an electric locomotive at the rate of seven

was carried by a platform car or pannier, and geared with a grooved driving-wheel thirty centimetres in diameter, which ran upon the rail. A rheostat to graduate the speed, switches to stop, start, and reverse the motor, and a seat for the conductor, were also carried by the locomotive, and ran on small grooved wheels. The current was brought to the dynamo by two insulated conductors, one connected to the rail,

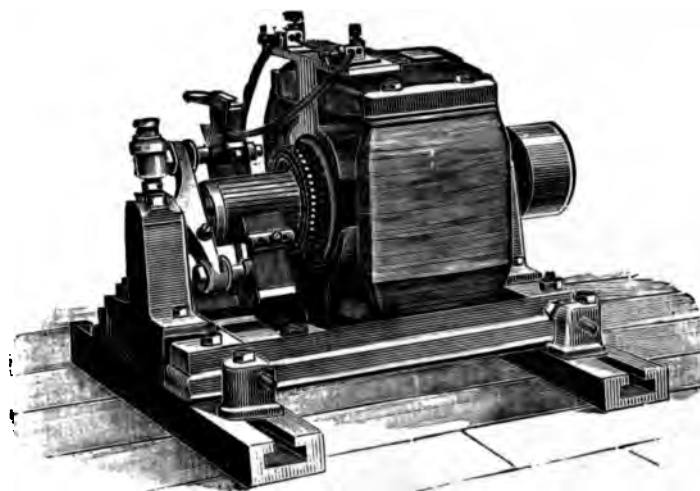


FIG. 62.—EXCITER, BLACKPOOL ROAD.

miles an hour. The total weight of the five cars and the electric locomotive was about a ton, and the maximum power required was three horse power. The dynamo of the locomotive was a Siemens D_6 , and the generator, which stood about 100 yards from the line, was a Siemens D_2 dynamo capable of developing from five to six electric horse power. It was driven by a Herman-Lachapelle steam engine. The total length of the line was 123 metres. It was built of forty-one rails, each three metres long, and comprised curves of seven and one-half metres radius. The locomotive dynamo

the other to the dynamo through small contact rollers in connection with the commutator. One switch was employed to start or stop the train by making or breaking the circuit; the other to reverse its motion by reversing the current. The rheostat, by interpolating resistance into the circuit, allowed the strength of the current to be varied and the speed of the train to be increased or diminished as the case may be. The work was carried out by Messrs. Siemens, and under the direction of M. G. Boistel. The economy of the working is of course largely dependent on local circumstances.

CHAPTER VI.

THE MODERN ELECTRIC RAILWAY AND STREET CAR LINE IN AMERICA.

THE narrative of invention and experiment given in Chap. III. has already detailed the numerous efforts made in America to work out the solution of the many difficult problems encountered in electric railroading. It has also shown beyond question that down to the time of the discovery of the reversibility of the dynamo, such work, no matter how ingeniously and persistently carried out, was doomed to failure. But with the advancing efficiency of the dynamo as a generator or as a consumer of current, and with the success of the Paris Electrical Exposition in 1881, came a revival of interest in the subject, and such a display of energy and ability in this field in America as to have brought the idea to triumphant realization within the brief period of five years.

To Mr. Stephen D. Field, a member of the distinguished Field family, the United States Patent Office has awarded priority of invention in electric railways in America. The papers of Mr. Field were filed in Washington on March 10, 1880 (a caveat was filed May 21, 1879); those of Dr. Werner Siemens on May 12, 1880, and those of Mr. Thomas Alva Edison, on June 5, 1880. These inventors were placed in interference, and it was not until last year that a declaration was made in favor of Mr. Field, on the combination of an electric motor operated by means of a current from a stationary source of electricity conducted through the rails. In view of what had been accomplished before Mr. Field secured his patent, it is altogether unlikely that he will be left in quiet enjoyment of the rights thus conferred. In fact, it is one of the peculiarities of electrical invention to develop colossal litigations, and we do not believe that electric railways will be any exception to the rule. Probably the electric motor companies now springing into vigorous existence will depend for future life not so much upon such fundamental patents as upon the

control of important details of construction and application.

A very interesting and authoritative account of the work of Mr. Field in this line appeared in the *New York Mail and Express* of August 2, 1884, and is here quoted in part:

“In his boyhood he showed a taste for mechanics and for electrical experimenting. He became a telegraph operator before he was sixteen, up among the hills of Berkshire county, where, after two removals across a continent, he at last proved the electric railway a success. In his 17th year the boy went with his family to San Francisco. He was first employed in California as an operator for the California State Telegraph Company. In 1865 he assisted in the construction of the Russo-American Telegraph Line, under the direction of Mr. Frank L. Pope, whom he had known as a boy in Massachusetts, and who afterward, as a patent solicitor, entered his application for a patent on the electric railway. It was in this year that he first learned of the successful solution of the problem of producing electric currents by mechanical means in the magneto-electric, and later in the dynamo-electric machine. During the year 1868 he constructed two electro-motors. The first—a rough model only—was made from an old magnet, some clock wheels, and stray pieces of iron he had picked up in the office. This model worked, and its success encouraged him to have a larger one constructed under his direction. Experiments with the first model proved to him that a galvanic battery would be too cumbersome and costly a means of producing a current ever to become practically useful, and he then endeavored by correspondence to find out the possibility of procuring large power machines. The object in constructing these first motors was to run street cars in San Francisco. Mr. Field's efforts to obtain a dynamo-electric ma-

chine were unsuccessful at the time. In 1871 he associated himself with Mr. Geo. S. Ladd and others in the organization of the Electrical Construction and Maintenance Company, of which he acted for nearly seven years as secretary and electrician. In 1877 he went to Europe, and there, at the workshop of M. Breguet in Paris, he saw some Gramme machines, which were exactly suited to the purpose of furnishing a current for his projected motor. On his return from Europe, two of these machines were ordered by Mr. Ladd, but after considerable delay the Californians were informed that Breguet would not send the machines, being afraid of invalidating some of his patent rights in the United States. Upon receipt of this information, a machine was immediately ordered from Siemens Bros., of London. At last their hopes seemed about to be realized and the long cherished project of applying electricity to locomotion was in a fair way to be practically tested, but another disappointment awaited them. The hoped-for dynamo was lost at sea on the way to San Francisco. Nothing daunted by this misfortune, they promptly ordered another machine, and at last, in the fall of 1878, it arrived. At the same time two Gramme machines were placed at their disposal by the Hon. Milton S. Latham. With these, experiments were made in a loft on Market street, and an elevator loaded with 1,500 pounds of coal was made to ascend and descend by their agency. The possibility of moving a load and of controlling and reversing the motion by means of an electric current supplied by a dynamo machine was now proved beyond a doubt. In February, 1879, Mr. Field elaborated his plans for an electrical railway and made drawings of a motor, which is substantially the same as that afterward put in operation by him at Stockbridge. In May of that year a caveat was filed by him in the United States Patent Office, which covered a claim for an electric tramway motor, the current to be supplied by a stationary source of power and connected with the rails. By means of a secondary machine on the motor the current would be converted into power to be supplied to the axles of the car by suitable gearing, and so the car would be propelled. The claim also covered a method of reversing the motion of the car by reversing the direction of the electric current.

"This was the very first official record of a plan for a dynamo-electric railway. In July, 1879, at the solicitation of friends, Mr. Field came to New York, and placed the matter of filing an application for a patent in the hands of his old friend, Frank L. Pope. This application was filed March 10, 1880.

"Up to this time the electric railway was all on paper. It was considered advisable by Mr. Pope that a working model should be constructed and operated, so in May of that year Mr. Field began at Stockbridge the building of a railway and an electric motor. The machines he first experimented with proved worthless, and he was obliged to stop work until he could procure funds to buy others. This he finally succeeded in doing, and in 1881 the road was in successful operation. Meantime the Siemens Brothers had been experimenting on electric railways in Europe, and had constructed several that worked well on a small scale. Mr. Edison had also been at work on the same problem, and built his well known little railway at Menlo Park. The inventions of the three investigators clashed, and on applying for patents they came in collision. It was soon found that the application of Siemens was subsequent to those of both Edison and Field, and it was thrown out. The trial between the two remaining competitors was long and tedious. The testimony was taken two years ago, but it was only last week that the final decision, awarding priority of claim to Field, was announced. The caveat filed in 1879, with its rude accompanying sketch, was shown to be, as has already been stated, the very first official record of a plan for operating an electric railway. Pending the result of the contest in the Patent Office, a consolidation of the Field and Edison interests was effected in 1883, and the Electric Railway Company of the United States came into existence."

The company here named was organized about the beginning of May, 1883. The project of exhibiting at the Chicago Railway Exposition of that year had been entertained, but it was not until two weeks before the opening of the exposition that it was definitely decided that the electric railway should form one of its features. Everything remained to be prepared. The locomotive was scarcely begun, and the track was not laid. But the work was put

under way and pushed with vigor. It is needless to say that the electric railway, under the circumstances, did not fairly represent the inventions of Messrs. Field and Edison, because the short time allowed to complete preparations left no other alternative than to make use of such electrical apparatus and material as could be readily and conveniently procured in the market without stopping to inquire too closely into its fitness for the purpose, and then

force of about seventy-five volts, with a current of about 150 ampères, through its normal circuit resistance of .5 ohm. Its weight was 2,700 pounds. The locomotive itself is shown in Fig. 63. It was named "The Judge," after Chief Justice Field, the uncle of its designer. The track ran around the gallery of the main exhibition building, curving sharply at either end on a radius of fifty-six feet. Its total length was 1,553 feet, or nearly one-third of a mile.

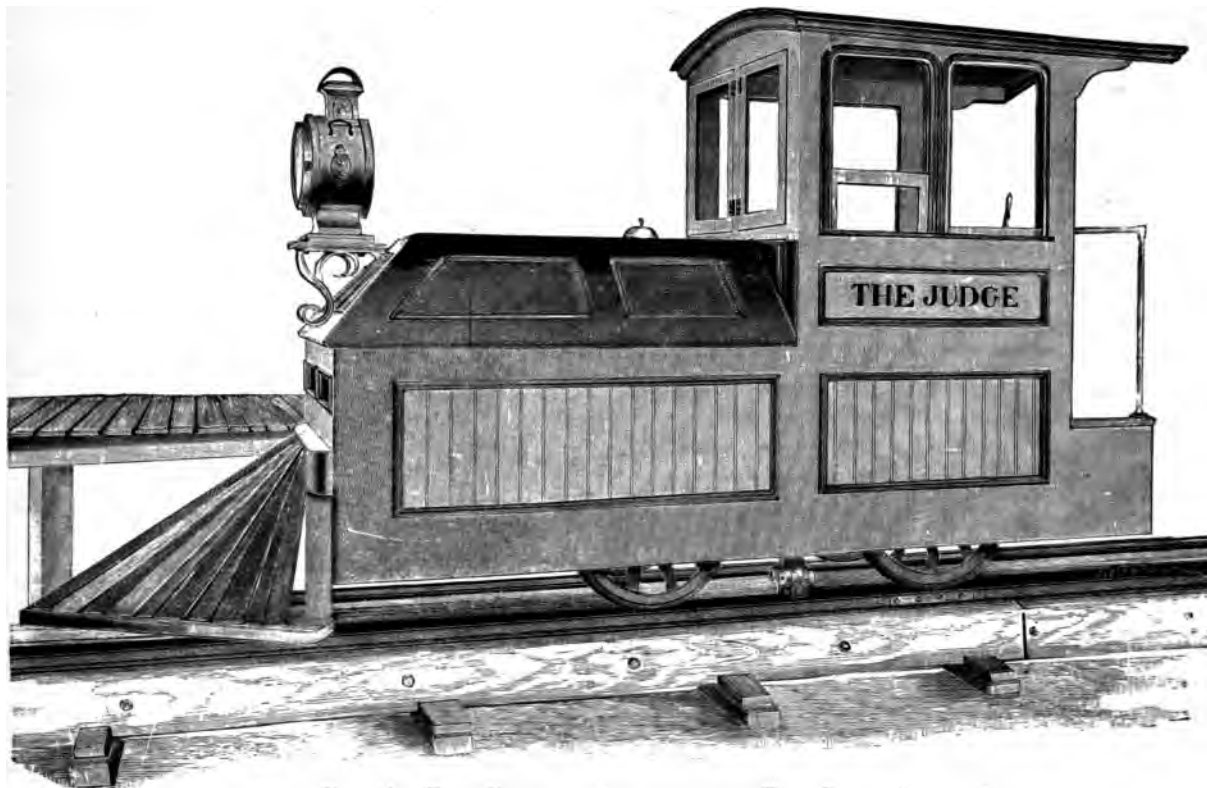
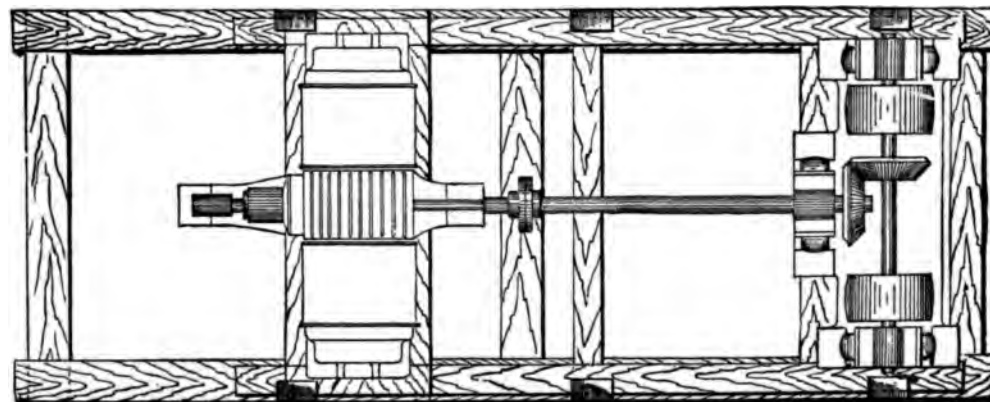
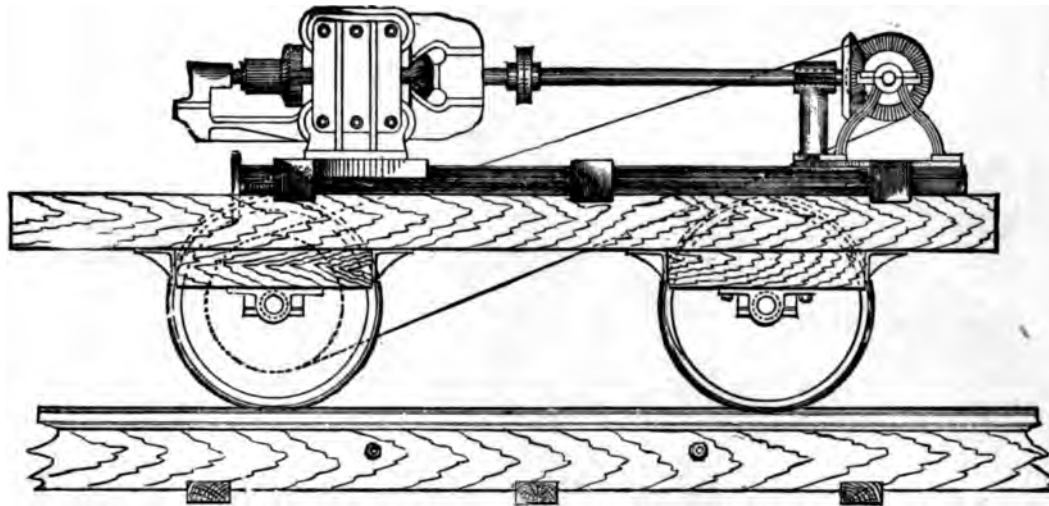
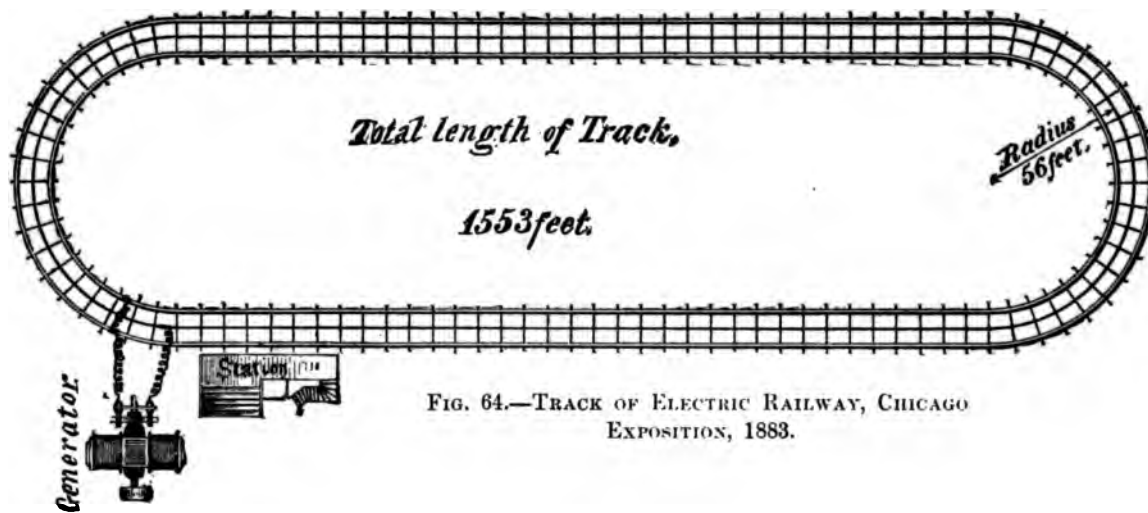


FIG. 63.—THE ELECTRIC LOCOMOTIVE, "THE JUDGE."

to design everything else to suit its electrical and mechanical peculiarities. Under the circumstances, it was impossible to hope for great efficiency or economy of results. It was, indeed, a matter of surprise that an electric railway was produced at all from the resources available at the time; and the execution of the novel task reflected great credit on Mr. Frank B. Rae and his assistant, Mr. Clarence L. Healy, who together attended personally to the many details. The same type of Weston shunt-wound machine was obtained from the United States Electric Lighting Company for generator and motor. At its normal speed of 1,100 revolutions, the machine had an electromotive

The track, Fig. 64, was of three-foot gauge, and had a central rail for conveying the current, the two outer rails serving as the return.

In order to secure a low resistance and proper connections between all the rails, a precaution made necessary by the low electromotive force of the generator, wires were laid under each rail. The inside rail was wired with No. 6 (B. & S.) bare copper wire and the outside rail with No. 8 iron wire. The central rail was also wired with No. 8 copper wire. A good contact was made with each rail by proper fastenings at the joints and also by laying the wire under the rails in the supporting plates, so that the weight of the rail rested upon it. These pre-



cautions practically reduced the resistance of the line to a value so small as to be inconsequential. It need scarcely be said that if the electromotive force of the current used had been higher these precautions would not have

by the generator, but in this case it meant a reduction of one-third.

The internal construction of the locomotive will be readily understood from the accompanying Figs. 65, 66, 67, and 68. Fig. 65 shows the

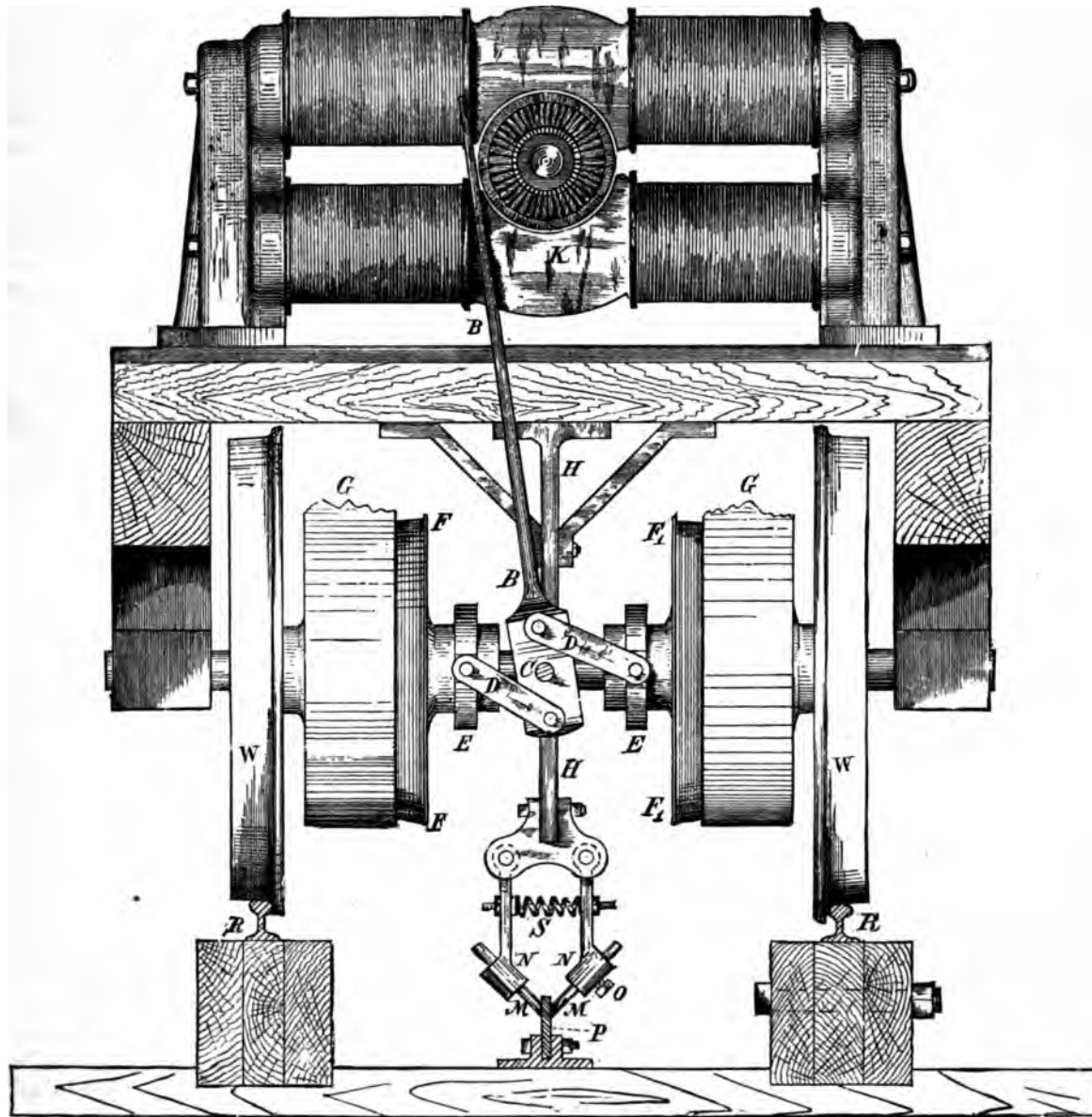


FIG. 67.—REAR ELEVATION OF "THE JUDGE."

been required, and a simple connection of the rails together without wires would have sufficed. With an electromotive force of 300 volts, for instance, to produce the same current, the addition of .25 ohm to the circuit resistance by the rails would not have produced a very marked lowering effect on the current delivered

locomotive in side elevation with its cab removed. Fig. 66 is a plan view of the same. These figures show the manner of transmitting the power from the armature of the motor to the driving wheels. The motor was placed cross-wise upon the frame. Its armature shaft was coupled to an extension shaft which was pro-

longed forward and transmitted motion by means of bevel gearing to a counter-shaft carrying two pulleys. From these pulleys the power was transmitted by means of belts to the loose pulleys on the axle of the drivers. It will be noticed that this arrangement threw the greatest weight directly over the driving wheels. The gearing up of the armature extension-shaft to the counter-shaft was made so as to reduce the speed three times. The pulleys on the counter-shaft were twelve inches in diameter, the driven or loose pulleys on the axle of the drivers were twenty-six inches in diameter, and the car wheels, or drivers, were thirty inches in diameter. The maximum speed which this gearing would produce was about twelve miles per hour, but the weakness of the gallery upon which the track was laid made it necessary to run the locomotive at a lower speed. The average speed maintained was eight miles an hour, the armature revolving at the rate of about 750 revolutions per minute.

It was found by Messrs. Rae and Healy in their preliminary experiments with the two machines that the condition of best efficiency of the generator was realized when the motor had attained its maximum speed, and that the power developed was greater at that time. From this they inferred that the proper moment to put the load on the motor was when it had reached its greatest velocity.

The mechanism by means of which this was accomplished was quite ingenious and simple, as seen in Fig. 67, which represents a rear end elevation of the locomotive without the cab. The loose pulleys $G G$ ran on the axle of the drivers $W W$, as previously stated, motion being transmitted to them by belts from the pulleys of the counter-shaft, as already shown. $F F F_1 F_1$ were cone friction pulleys fitting into the interior of the rim of the loose pulleys. These friction pulleys revolved with the shaft, being connected thereto by means of keys and keyways, which were loose, however, so that the friction pulleys could be free to slip lengthwise on the axle as they revolved. The hub of each friction wheel $F_1 F_1$ carried a collar $E E$ which was connected by arms $D D$ to a lever B fulcrumed at C on a projection from another collar fitted around the shaft. The operation of this form of friction clutch will be readily understood. In the position shown, the friction cones $F F F_1 F_1$ are removed from the

pulleys, which are free to move loosely upon the axle. But upon moving the lever B to the right the friction cones are both moved outward from the centre, and caused to engage the inner surface of the pulleys, and thus the motion of the loose pulleys is communicated to the drivers $W W$.

As already stated, the central rail of the track formed one conductor and the two outside rails $R R$ the other. The device for "picking up" the current was quite ingenious, and is also shown in Fig. 67. It consisted of a kind of inverted vise firmly bolted to an arm $H H$ projecting downward from the frame of the locomotive. The jaws $N N$ of the vise were each perforated with three holes directed ob-

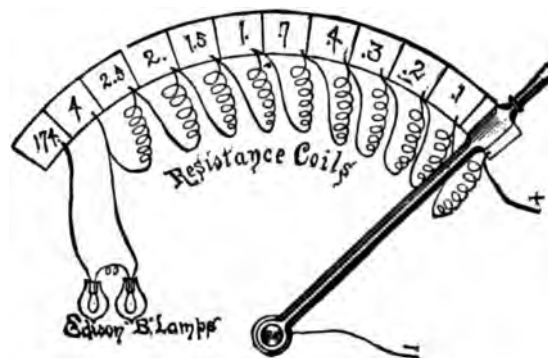


FIG. 68.—SPEED REGULATOR.

liquely downward and inward, through which bundles of phosphor-bronze wire passed, being securely fastened and held by a screw O . A spring S extending between the arms of the vise served to bring the two brushes $M M$ into close and sure electrical contact with the central rail P . The wire being stiff and firm, the contact was equally certain whether the locomotive was moving forward or backward.

An important feature of this electric locomotive was the means by which the speed could be regulated at pleasure by a "throttle-valve" arrangement resembling that found in every American locomotive, and which answers the same function; namely, to control the amount of force put in action. The nature of the device was as simple as it was efficient, and consisted simply in a lever, Fig. 68, by the motion of which the resistance of a suitable rheostat could be thrown in and out of the main circuit with the evident result of controlling the amount of current flowing therein. The lever

was placed horizontally and could move over contact segments disposed in a circle. These segments were insulated from each other, but they were connected by coils of iron wires so as to make a certain resistance, and possessing sufficient area of section to remain cool. Thus, when the lever was in the position shown in the figures, there was no resistance included in the circuit. When the lever was moved forward to the next segment, the resistance added to the circuit was .1 ohm. On moving to the next the resistance added was .2 ohm, and so on, the amount of resistance included in circuit when the lever touched each segment being in Fig. 68 indicated by the figures thereon. The rheostat comprised two Edison *B* lamps of 85 ohms each, so that the total resistance when the lever touched the last segment was 174 ohms. It will be readily understood that by means of this device the amount of current in the main circuit could be easily varied.

The high resistance necessary at starting to cause the magnetic field of the generator to magnetize itself was readily afforded by this rheostat on closing the circuit. Another interesting feature of the Chicago electric locomotive was the device by means of which the current was reversed at the motor when it was desired to make the locomotive move backward (Fig. 69). The lever *J* caused the wheel *HH* to turn on the armature shaft *G*. This wheel geared with two wheels *E F*, to which were fastened arms *C C*, *D D*. These arms carried brush-holders and brushes *A₁ A₂ B₁ B₂*. The function of the device was simply to change the relative direction of the current through the armature of the motor. In the position shown in the figure the positive brush *B₂* touched the commutator at the left-hand side, while the negative brush *A₂* touched it at the right-hand side. On moving the lever *J* as far as *K*, the brushes *A₂ B₂* broke contact. In this condition the motor was out of the circuit and received no current. This is just the same as when the reversing lever of a steam locomotive is moved half way, thus cutting off the steam entirely by preventing the motion of the slide-valve. On moving the lever still further, the brushes *A₁ B₁* came in contact with the commutator of the motor, so that the positive brush *B₁* touched the right-hand side of the commutator and the negative brush *A₁* the left-hand side, instead of the opposite. The re-

sult was necessarily a reversal of the direction of rotation of the armature of the motor.

The locomotive was also provided with an electric bell. This bell had a resistance of 350 ohms, and was rung by a switch which

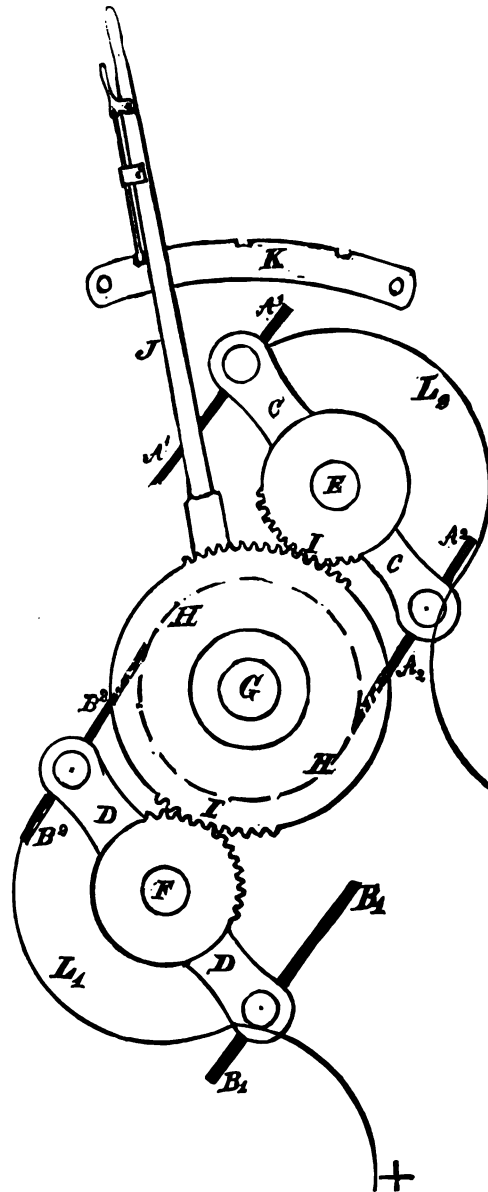


FIG. 69.—REVERSING MECHANISM.

placed it in parallel circuit with the motor. Its high resistance prevented the diversion of the current from the motor in any appreciable quantity.

The locomotive was twelve feet long and five feet wide. Its total weight was about three tons. It was intended to be run with two

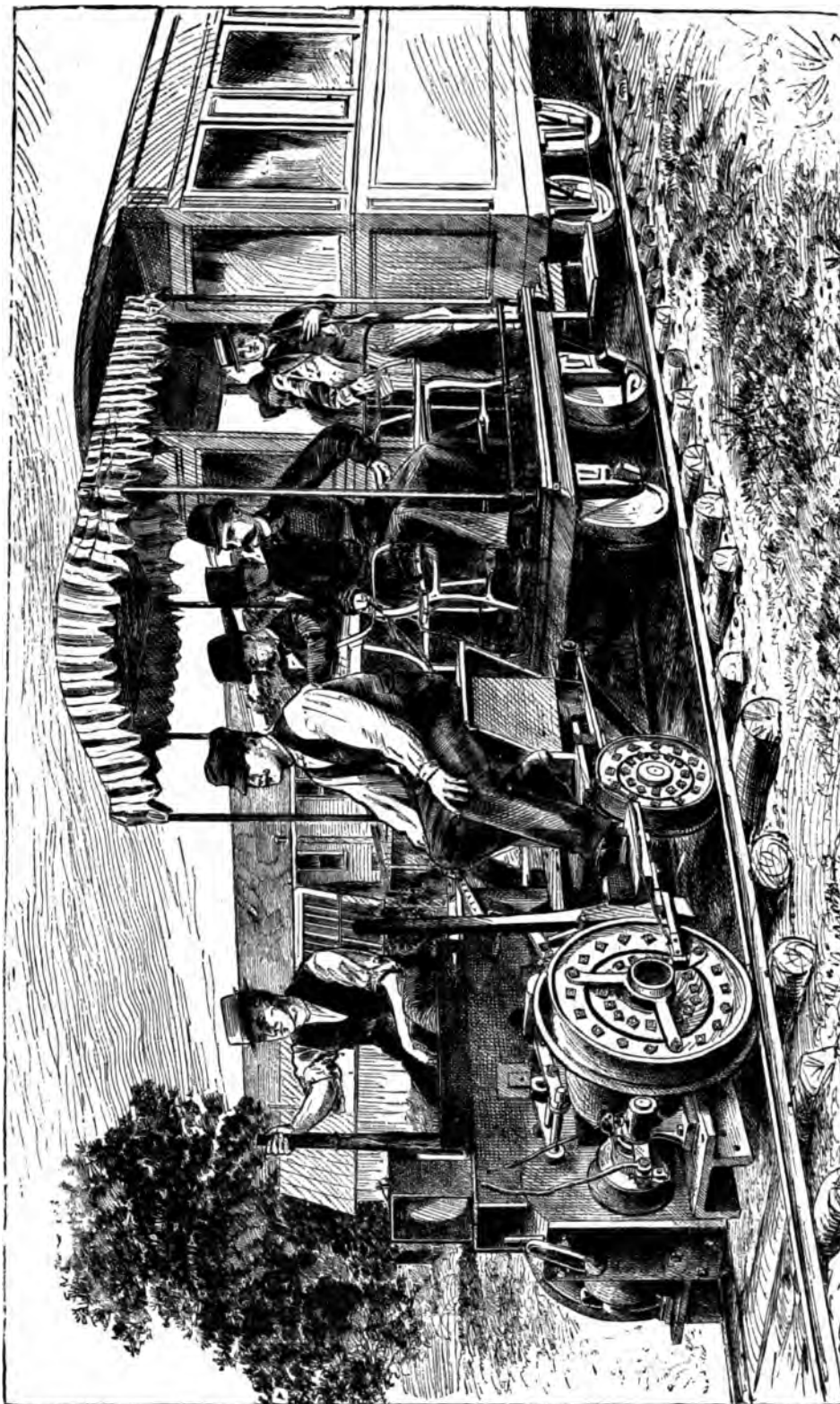


FIG. 70.—EARLY EDISON ELECTRIC LOCOMOTIVE.

passenger cars, but it was found upon inspection that the gallery was too weak to stand the strain. Even after the gallery had been strengthened, it was not deemed expedient to exceed a speed of nine miles an hour.

The Chicago electric railway was the first constructed in this country for business purposes, and, considering the short lease of active

run in all 118½ hours and 446.24 miles. It carried 26,805 passengers. It was afterwards sent to the Louisville Exposition during the same year, and there carried a large number of passengers.

Mr. Thos. A. Edison's work in electric railroading dates back to the spring of 1880, although his ideas on the subject had been made known

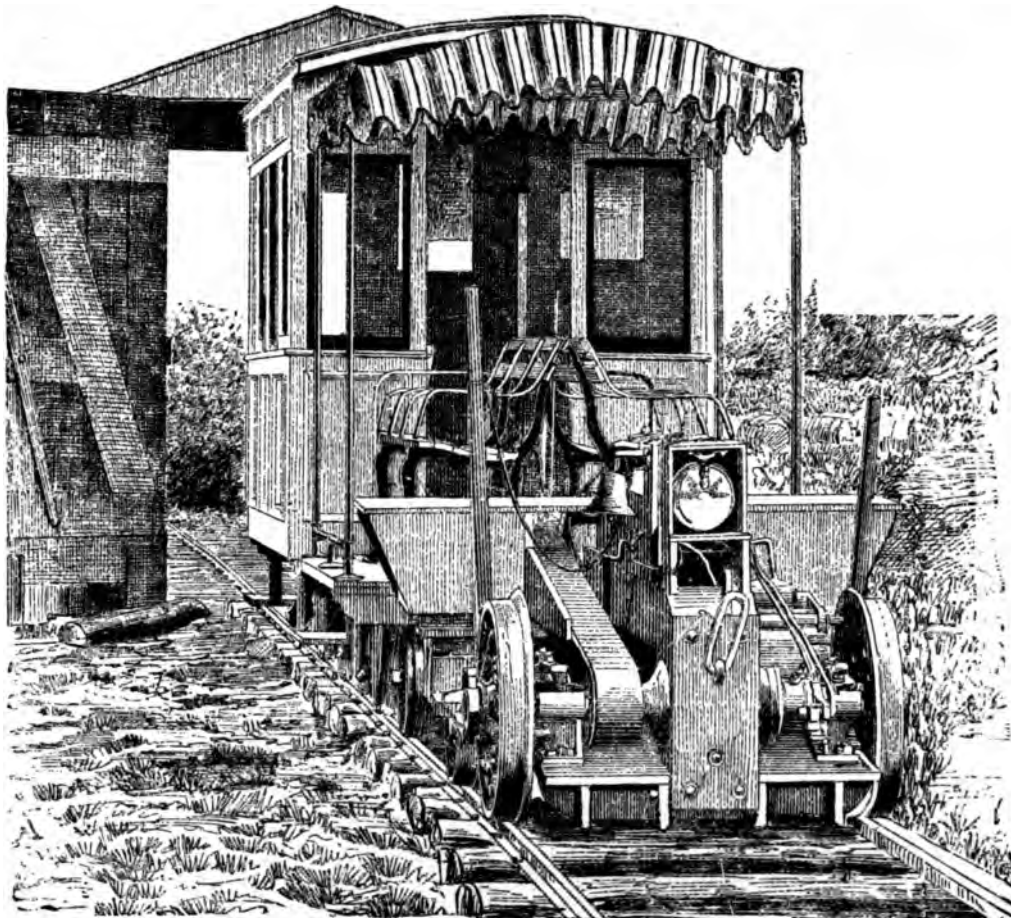


FIG. 71.—EARLY EDISON ELECTRIC LOCOMOTIVE.

life which was left to it after it was finally completed and put in operation, its success was most surprising. Owing to delay in receipt of the report of the engineer intrusted with the task of strengthening the gallery, the road was not permitted to operate for business until June 9, 1883, but experimental trips of the electrical locomotive were made daily from June 2.

Upon June 5 "The Judge" and its attached car loaded with sixteen passengers was started around the track. The railway was opened for business on June 9 and closed June 23, having

at least a year earlier. In 1880, he built a track at Menlo Park, N. J., near his laboratory. This line was less than half a mile in length, and no special pains were taken in the preparation of the road-bed. The early locomotive employed is shown somewhat roughly in Figs. 70 and 71. The generator and motor were of a type then made by Mr. Edison, but not now in use. The current was led to the track by two copper wires, one to each of the rails, which were thus positive and negative, and were insulated from each other. The armature of the motor was

connected in the usual manner with the driving wheels, and made four revolutions to their one. Fig. 72 shows the Edison locomotive as afterwards improved.

Towards the close of 1883, the experiments of Mr. Leo Daft, the electrician of the Daft Electric Light Company, began to attract attention; and the ability and perseverance since exhibited by

curve having a radius of about 290 feet; but the tests as a whole gave great encouragement to Mr. Daft's friends.

We show in Figs. 74 and 75 a plan and elevation of the locomotive "Ampère," used on the Saratoga road, and still in operation elsewhere. It is about ten feet in length, and rests upon four wheels. The motor is situated at the rear

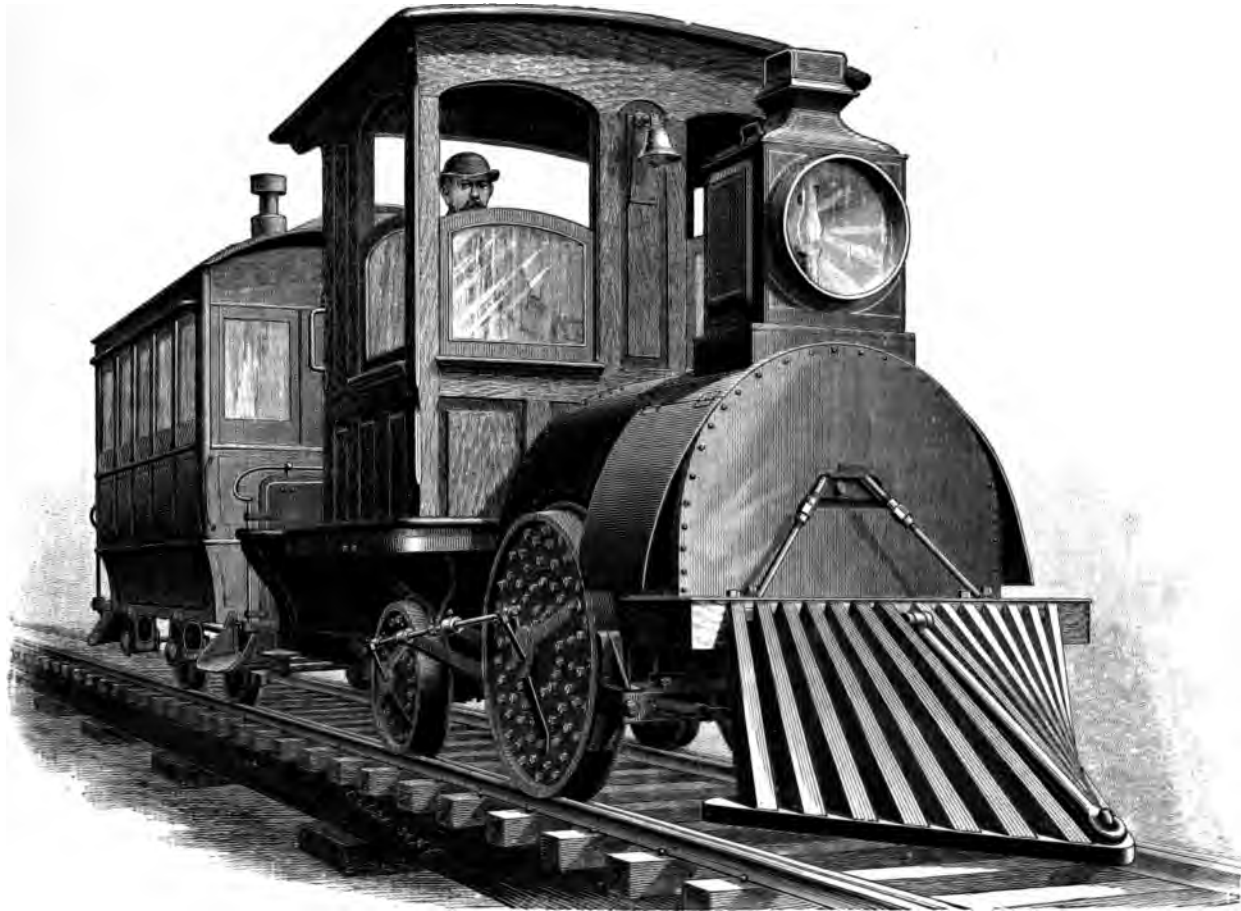


FIG. 72.—IMPROVED EDISON ELECTRIC LOCOMOTIVE.

Mr. Daft in the various application of electric motors have given him great and deserved prominence to-day. At first the trials of the Daft motor were made on the grounds of the company's works at Greenville, N. J., and there proving successful they were renewed on the Saratoga and Mount McGregor Railroad in November of 1883. The line is about twelve miles long, and abounds in sharp curves and steep grades. During its first trip there, the motor "Ampère," Fig. 73, being too light for the pull given it, jumped the track on a

end of the platform, and is incased in a box to prevent injury from dust.

The armature of the motor has a special construction in order to deliver the large current required. Mr. Daft achieves this by grouping equidistant along the periphery of his annular revolving armature as many superposed bobbins as the case in point demands, and fagoting their terminals before leading them to the segments of the commutator to which they respectively belong. Each one of a group of bobbins, on the armature, crosses the magnetic field at

approximately the same instant, and the current developed in them collectively is of a potential due to their few convolutions and of a quantity proportional to the enlarged channels of escape.

At each end of the armature shaft there is keyed a pulley, from which belts run to the large central pulleys mounted on the counter-shaft, which is situated midway between the driving wheels. Another set of belts connects the latter with the counter-shaft, and the reduction of speed from the armature pulleys to the drivers is in the ratio of eight to one. The two small wheels shown as resting on the rail are phosphor-bronze contact-wheels; they bear upon the central rail, and through them the current is taken up. They are fixed upon springs so arranged that they can mount any small obstacle on the rail; but, being two in number, one of them is always in contact, thus insuring an uninterrupted current.

The driver of the locomotive is provided with a seat, and situated directly in front of him are three switch-boxes. The one toward the right is the main switch by which the current can be turned on or off. The regulation of speed in the "Ampère" is effected entirely by means of the "multi-series switch," constituting the middle box, which is so arranged as to effect an almost endless variety of changes in the intensity of the field of force, without the use of idle resistance. In order to accomplish this, some iron wire is employed in the outer coils of the field magnets so as to obtain the required resistance without too greatly exceeding the magnetic limit.

The brakes of the "Ampère" are controlled by the third switch shown, and a mere turn of the hand causes them to act with any required degree of intensity. The brakes themselves are of the so-called "pendulum" type. As will be seen, they are suspended from the frame of the car and swing freely on a bolt passed through an eye at their upper ends. The suspended frame carries an electro-magnet wound with stout wire, and when the current is switched into the latter the magnet immediately follows the attraction of the wheel, pressing against it and exerting a powerful grip. Situated at the side of the driver there will also be seen a lever, by means of which the locomotive can be sent forward or reversed at will. This is accomplished through the medium of

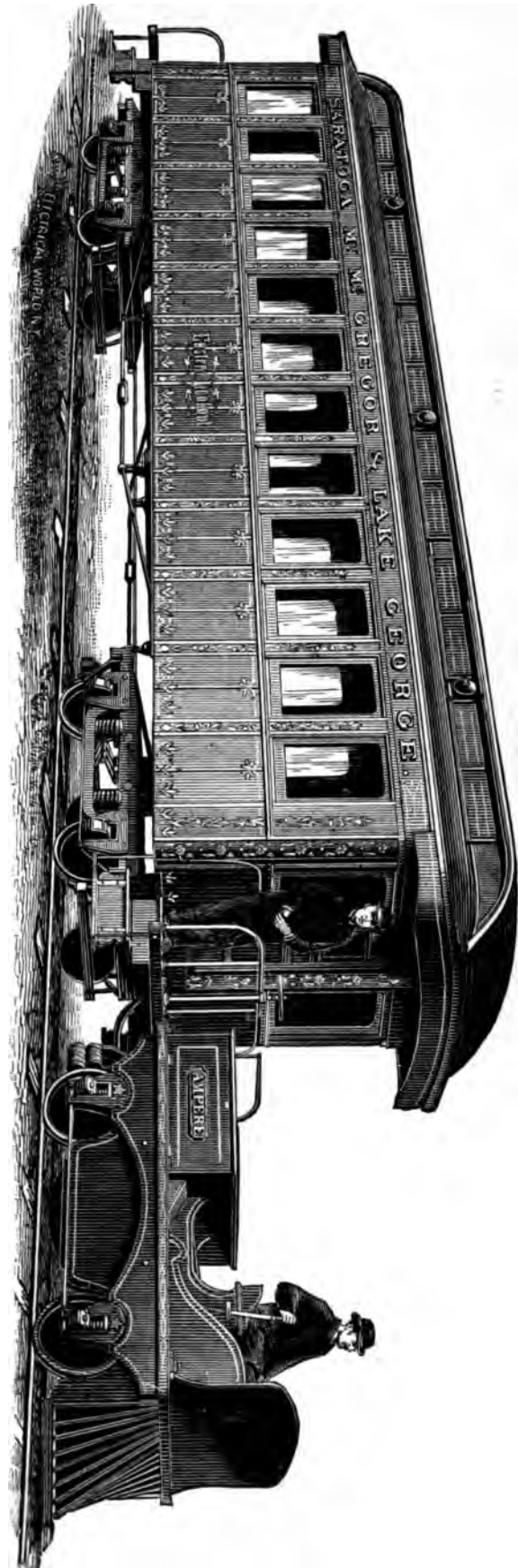


FIG. 73.—DAFT Electric Locomotive "AMPÈRE."

four brushes arranged about the commutator and placed equidistantly apart. The lever has two rods at its lower extremity, which connect with two brushes each, and by this means either

starting point. The track was laid with thirty-five pound rails, in addition to which a central track of similar rails was laid upon blocks of hard wood, saturated with resin, which were

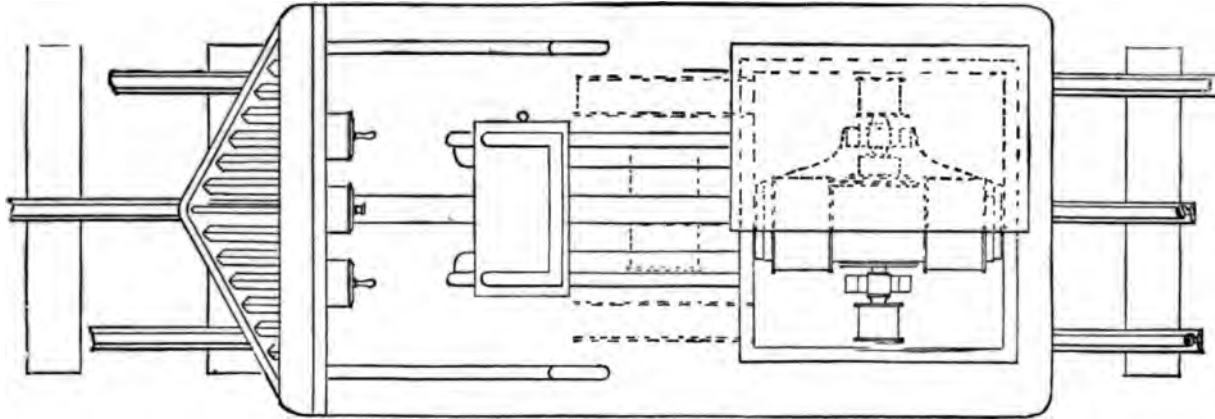


FIG. 74.—PLAN OF "AMPERE."

pair can be put in contact with the commutator with the result above mentioned.

From the above description it will be seen that the locomotive presents all the features of a well executed system, and some details of the test at Saratoga, mentioned above, will there-

spiked down to the ties at intervals of six or eight feet; upon this ran the phosphor-bronze contact-wheels.

The generators consisted of two of Mr. Daft's old type No. 8 series machines, which were operated about 100 yards from the track by a

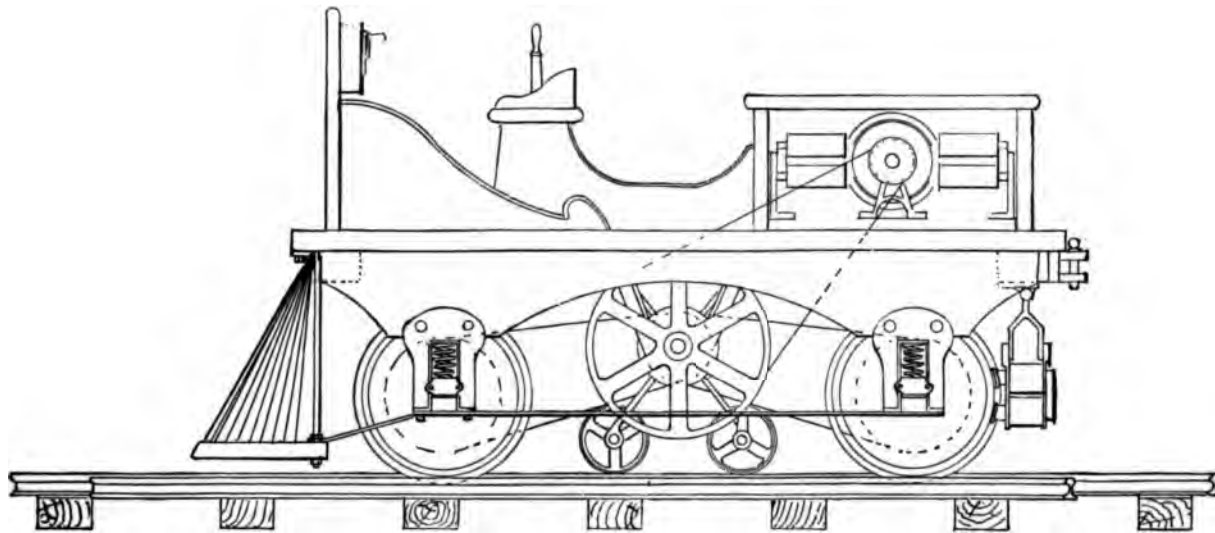


FIG. 75.—ELEVATION OF "AMPERE."

fore prove of interest. On that occasion the track upon which the "Ampère" ran was about one and one-quarter miles long, being part of the main track of the Saratoga and McGregor Railroad, and included a very sharp curve and grade combined, about one mile away from the

twenty-five horse-power Buckeye engine situated in the Saratoga Rubber Works. The Daft machines will be found fully described in Chap. IX.

The calculated resistance of the line was about two ohms. The actual resistance could

not be measured, owing to the continual earth disturbances. By other tests, however, it was evidently very low. The resistance of insulation between central and outside rails, when the ground was wet from a recent rain, reached about 130 ohms, showing a leakage, from that source, of about one and one-half per cent. of current with motor under maximum load. The resistance of motor, as given below, is taken while at rest; it is of course higher with the motor in motion, as will be readily understood.

The following are some of the results of the tests made at that time:

Internal resistance of primary machines in parallel,	0.42 ohms.
Resistance of motor,	from 1.04 to 5 "
" " line (calculated),	0.2 "
" " track-insulation,	130 "
" " motor arranged for low speed and great traction at start—at rest,	3.10 "
Resistance of motor arranged for highest duty,	1.15 "
Mean electromotive force over high resistance shunt at start,	100 volts.
Electromotive force, with lowest external resistance employed,	130 "
Current, when ascending grade,	80 ampères.
Revolutions per minute,1050

The actual performance of the "Ampère" consisted in hauling an ordinary railway car weighing ten tons, containing sixty-eight persons in addition to the motor, which weighed two tons, and had five persons upon it. The speed obtained was eight miles per hour upon a track having a gradient of ninety-three feet to the mile, and included a curve of about 20°. This showed a maximum duty of about twelve horse power, and, although the actual efficiency was not determined, it ought to be mentioned that the twenty-five horse-power engine, which actuated the primary machines, was also doing other duty in the factory.

During 1884 Mr. Daft built and equipped a small line on one of the piers at Coney Island. This did not go into operation until part of the season had passed, but it carried 38,000 passengers. A little later another Daft road at the Mechanics' Institute Fair in Boston carried between 4,000 and 5,000 passengers weekly for more than a month. Its motor "Volta" was then taken to the New Orleans Exposition, where a Daft road was put in operation between the main building and the government building, a

distance of nearly a fifth of a mile. It was there run regularly by a No. 4 Daft generator, driven by a Payne engine, and again carried several thousand passengers.

In the early part of the spring of 1885 the Baltimore Union Passenger Railway Company, hearing of the rapid progress of the Daft Electric Light Company with its system of electric railways, and wishing to increase its carrying capacity, investigated the matter. Satisfied with the completeness of the system, an order was at once given to construct two motors and equip the Hampden branch of the lines named.

It was some time, however, before definite plans were settled upon; but about the middle

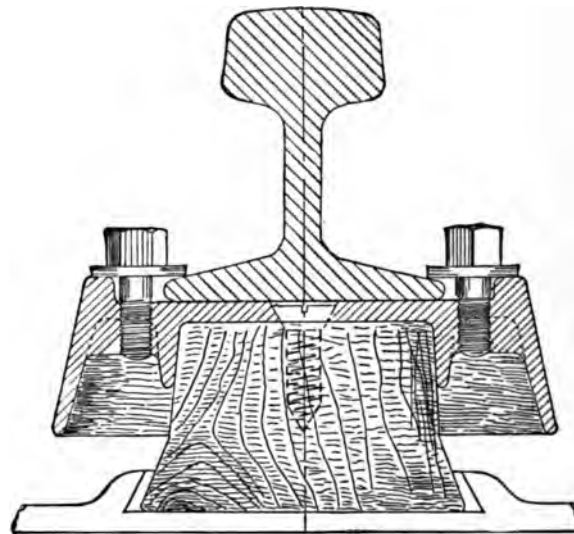


FIG. 76.—METHOD OF RAIL INSULATION.

of April work was begun both at Baltimore and at the Daft works. On June 10 the first motor was shipped. The Baltimore Union Passenger Railway Company, Edgar M. Johnson president, T. C. Robbins general manager, is one of the largest in the city. It operates twenty-five miles of roads, and has within its stables nearly 400 horses. The Hampden branch is just two miles long, runs through the villages of Hampden, Mt. Vernon, and Woodbury, aggregating some 15,000 inhabitants, and is one of the hardest bits of line the company operates. Starting from the main terminus on Huntingdon avenue, there is scarcely 300 feet of level road the entire length. The village of Woodbury, though not two miles distant, is 150 feet higher than Baltimore. Grades and curves

constitute the main features; in fact Mr. Daft appears to disdain an ordinary track on the level. The heaviest grade on a tangent is 319 feet, and on a curve 352 feet per mile. The sharpest curve has a radius of but 50 feet, the largest 89 feet.

To equip this road the joints of the outer rails were perfected, and a third rail, an ordinary 25-lb. T rail similar to the outer rails, was laid, with the Daft patent insulator, midway between the outer rails.

The insulator, Fig. 76, consists of an iron shoe of diamond shape, eight inches long, three

the main terminus a new building, forming one room 20 by 40 feet, was built for the engine and dynamo. The engine is a 16 by 24 inch Atlas engine, made at Indianapolis. The boiler and all fittings are from the same firm.

The dynamo is one of the Daft Company's largest. Its total weight is 4,200 pounds and its maximum capacity is 300 ampères at 125 volts electromotive force. A nine-inch double belt connects direct from the ten-foot fly-wheel on the engine to a fifteen-inch pulley on the dynamo. Switches, regulators, automatic cut-outs, and all other safety devices necessary for a complete system were put in, as precautionary measures against every possible form of danger or trouble.

The construction and appearance of the motor for this line is fairly represented by Figs. 77 and 78. Its name, as will be seen, recalls the important connection of Professor Morse with the city of Baltimore.

Over all, the motor measures 12 ft. 6 in. by 6 ft. 6 $\frac{1}{2}$ in. The frame is constructed of 2 $\frac{3}{4}$ by 19 in. ash, bolted together and braced with four-inch angle iron. The inside dimensions are 9 ft. 1 $\frac{1}{2}$ in. by 5 ft. 11 $\frac{1}{2}$ in. The wheels are standard car wheels, but with specially deep flanges and wide treads; they

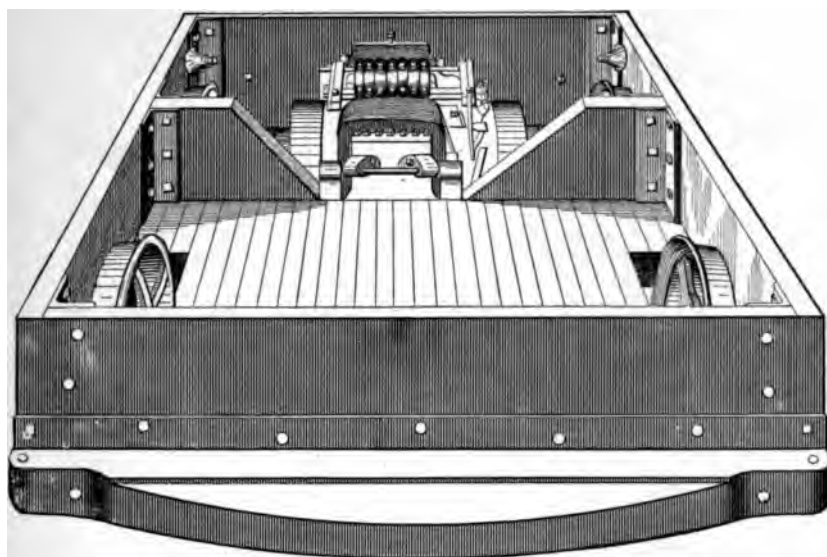


FIG. 77.—DAFT MOTOR, "MORSE."

and one-half inches wide and one-quarter inch thick, with two converging ways upon one of its surfaces.

Wedged between these ways is a round block of wood of truncated cone shape, with a height of two and one-half inches. Upon this block is screwed a round iron cap. This is four and one-half inches in diameter and two inches deep. Coming within three-quarters of an inch of the iron shoe, it thoroughly protects the wood block. The rail placed on the cap is held in position by two bolts screwed into the cap. The difficulties of constructing such a work, it being all entirely new, were many, but they were met and successfully overcome.

The centre rail forms the outgoing lead, the two outer rails with the ground being the return. The resistance of such a line averages less than .3 of an ohm, with perfect joints. At

are thirty inches in diameter and have five foot centres.

The cab is built in the ordinary manner. It is finished inside with ash and black walnut, and is very neat and substantial. The receiving machine is a compound series motor capable of delivering eight horse power. Its total weight is 1,100 pounds, the armature being 196 pounds. The compound nature of the field permits of a wide range of resistances, and hence of magnetic strength of field. As the armature-speed depends, in a certain sense, upon this field, a perfect means of regulation of speed is obtainable.

Motion from armature shaft to car wheels is obtained by internal gears. Upon each end of this shaft a three-inch phosphor-bronze gear is keyed.

These engage with large gears, twenty-seven inches in diameter, fastened to the axle of the

driving wheels. By this arrangement the energy of the armature is utilized practically almost directly upon the periphery of the driving wheels. The speed of armature to drivers is as nine to one. Therefore as the wheels must make 509 revolutions to the mile, the armature makes 4,581 revolutions.

The ratio of peripheral speeds, however, of armature to drivers is as 3.27 to 1.

As high speed is the normal condition of an armature, no real sacrifice is made to gain leverage. The speed of armature for eight miles an hour, the limit the law allows, is 610. To take up all back-lash of gears, the motor is arranged with pivoting bearings at one end and a regulating screw at the other, both resting upon heavy pieces of rubber. This pivoting arrangement is again advantageous in case of repairs, or inspection, through accident; the large gears being held in place by means of a set screw and long spline. On loosening the set screw, they can be easily removed along on the axle, freeing the small gears. The motor then can easily be raised to a vertical position allowing free inspection. The total weight of the "Morse" is about 4,200 pounds.

The wiring and controlling mechanism is equally as simple and substantial. No. 4 B. & S. underwriter's wire is used throughout. It is run in grooved sheathings, and covered so that no wire is to be seen excepting at the motor. Every precaution has from the first been taken to obviate any danger arising from moisture or short-circuits.

The controlling device consists of four heavy brushes bearing upon a stout frame of soapstone, carrying broad and properly shaped contact pieces. This whole is enclosed in an 8 in. by 16 in. iron box, with an ordinary engineer's handle and guide.

Four movements are made, controlling the combinations of the field magnets, which vary from .39 to 3.75 ohms. The resistance of the armature is .24 of an ohm. By proper connections with the switch, it can be readily seen that the motor can be slowly and easily started, stopped, or run. By turning a small handle placed just to the left of the main switch, either to the right or

left, one of two pairs of brushes is brought to bear on the commutator, thus giving the directive motion to the armature, and obviously to the car.

Another switch just to the right of the main switch is a dead cut-off controlling the main current coming from the contact wheel. This is placed underneath the car, and consists of a heavy fourteen-inch wheel of phosphor-bronze, free to slide four inches to the right or left, and rotating freely upon its shaft. A deep groove is cut into the rim, fitting the centre rail. By a

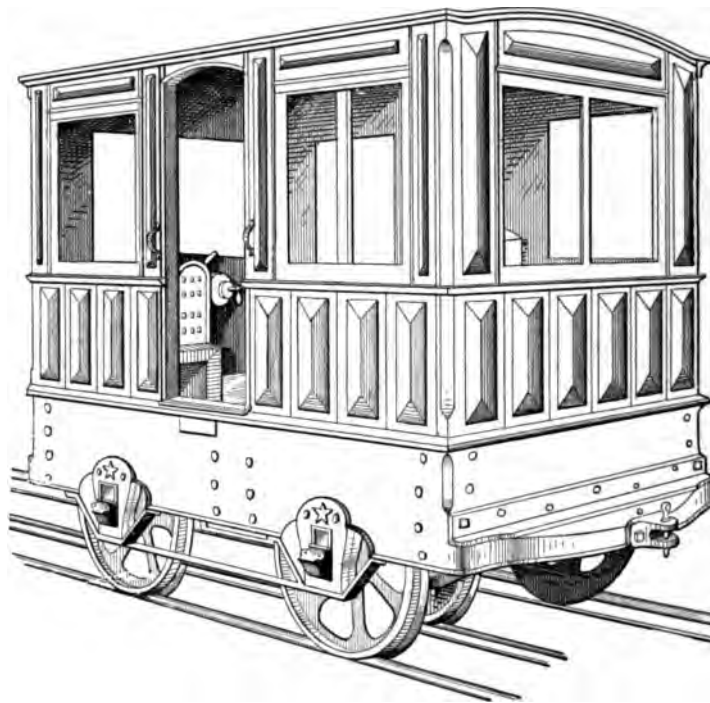


FIG. 78.—DETAILS OF THE MOTOR "MORSE."

lever and a heavy spring a constant pressure tends to keep the wheel down on the rail. By this arrangement the wheel can adapt itself to every curve or change of level of the rail. An ordinary hand brake is placed in the car just to the left of the switches. By this handy arrangement, one man, with a little practice, can easily manipulate the switches and brake, and so control the car.

It may be here stated that for much of the information given of the Daft system, we are indebted to Mr. G. W. Mansfield, to whose efficient hands Mr. Daft has generally intrusted the execution of his plans.

This equipment went into service on August 8, 1885, from when until now the road has been

dependent upon electricity as its sole motive power.

During the first six months of operation several storms of peculiar severity visited the region, but contrary to the predictions of all the visiting electricians the road did not suffer any more interruption to travel than was experienced on ordinary roads from the same

drivers that the service is better at such times than in fair weather.

The road was at first supplied with two motors only, the "Morse" above described and the "Faraday," but these being found insufficient, both in size and number, for the greatly increased traffic, the more powerful motors "Ohm" and "J. L. Keck" were added early

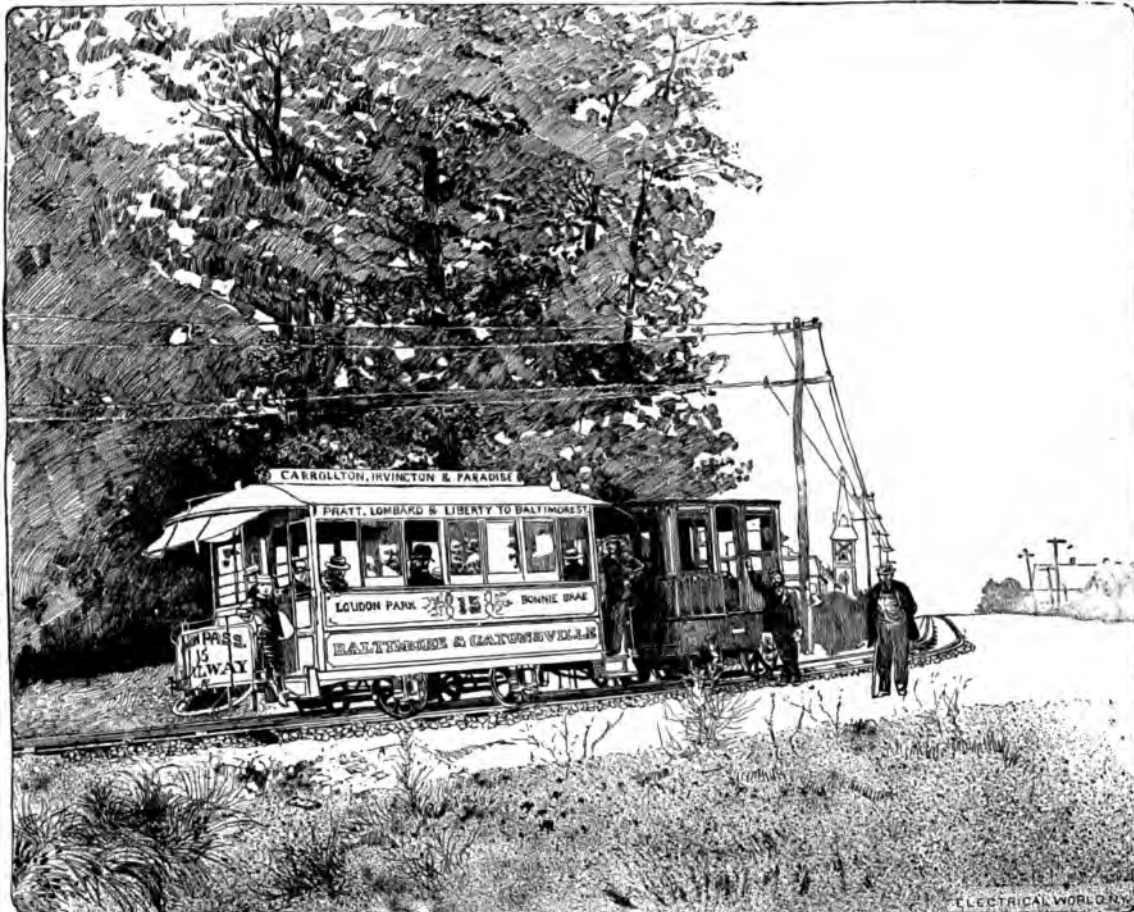


FIG. 79.—CURVE ON THE BALTIMORE ELECTRIC STREET RAILWAY.

cause. Several times parts of the track have been actually submerged by rain, when the spectators have been treated to the extraordinary spectacle of an electric motor hauling a heavily loaded car, with the flanges of the driving wheels deep in the water! At such times, of course, the insulation was somewhat impaired, but never so much as to cause any marked change either in the speed and capacity of the motors or the load on the station dynamo. Indeed it is a cherished illusion of the motor

in 1886, and the trains are now despatched at intervals of twenty minutes, instead of half hourly, as before.

Each motor performs an average daily run of seventy-five miles, which, considering the extraordinary grades and curves of the road, is very heavy duty for a mechanical tractor. The General Manager of the Baltimore Union Passenger Railway Company, Mr. T. C. Robbins, has made many improvements in the road since the introduction of electricity, and has through-

out shown a rare intelligence which, together with his enthusiastically progressive temperament, has largely contributed to the successful prosecution of the work. A late survey of the road shows the heaviest grade to be that entering Roland avenue, about one and one-half miles from the station, of 348 feet per mile on a curve of 75 feet radius, but there are several gradients of over 250 feet per mile, and curves ranging

As a test for himself, Mr. Robbins once sent to the city for one of their heaviest cars, . . . lbs. 5,100
 And carried a load of eighty-one persons over the road (say 81 × 125 pounds), . . . lbs. 10,125
 The weight of the motor used was . . . lbs. 4,500
 Total, . . . lbs. 19,725

Thus he says that 19,725 pounds were carried over the road by one motor of . . . lbs. 4,500

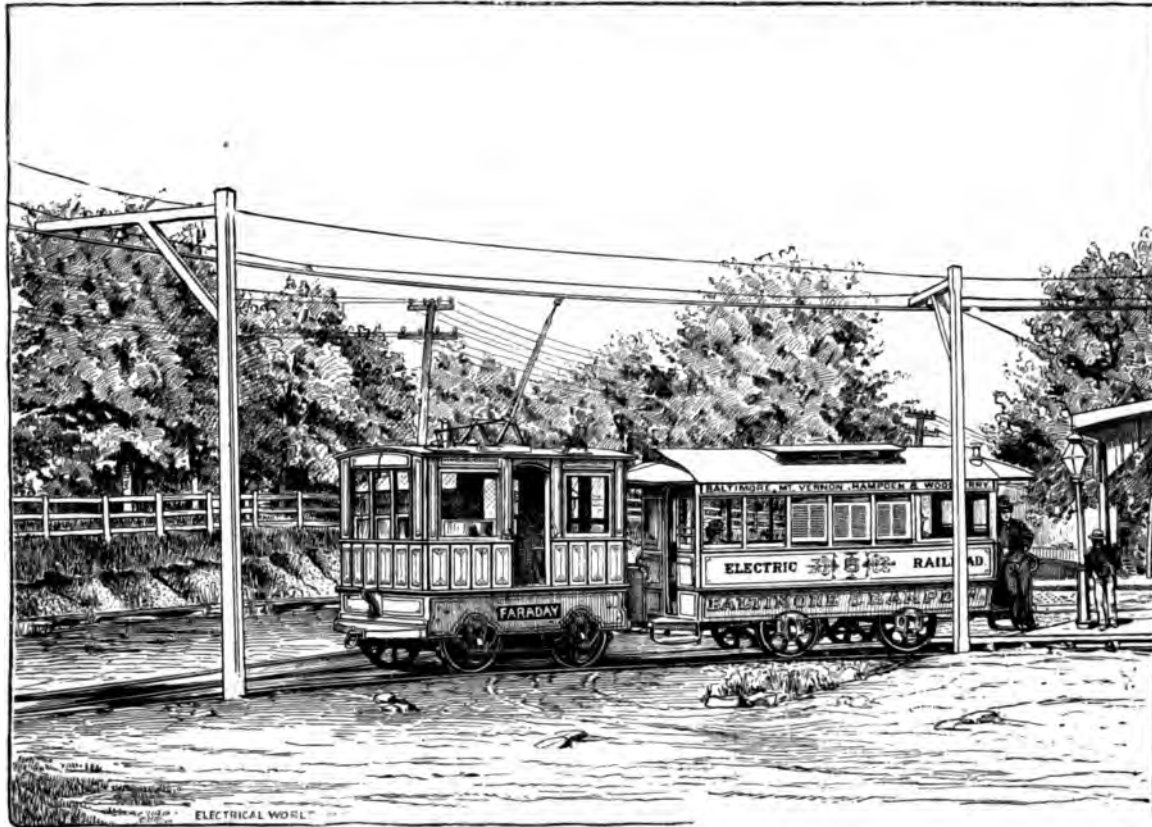


FIG. 80.—OVERHEAD CONDUCTOR ON BALTIMORE RAILWAY.

from 40 to 90 feet radius. Fig. 79, an accurate reproduction of a photograph, represents the motor "Morse" on the curve No. 5, which combines a gradient of 275 feet with a curve of 89 feet radius. Mr. A. H. Hayward, the electrician in charge, also superintended the Daft Electric Railroad at New Orleans. It is now proposed to extend the line, with overhead conveyance of the current.

As some figures may be asked for, the following will be found of interest. They were published several months ago:

His engine and boiler cost, approximately, . . . \$2,400
 His two motors cost, approximately, \$3,000 each, . . . 6,000
 Total, . . . \$8,400

There is also the expense of conducting rails and wires, insulation, protection, etc.

His expense of running per day is 1½ tons of soft coal, . . . \$4.75
 Engineer and fireman at power station, . . . 4 50
 Or, excepting oil, waste, wear and tear, per day, \$9.25

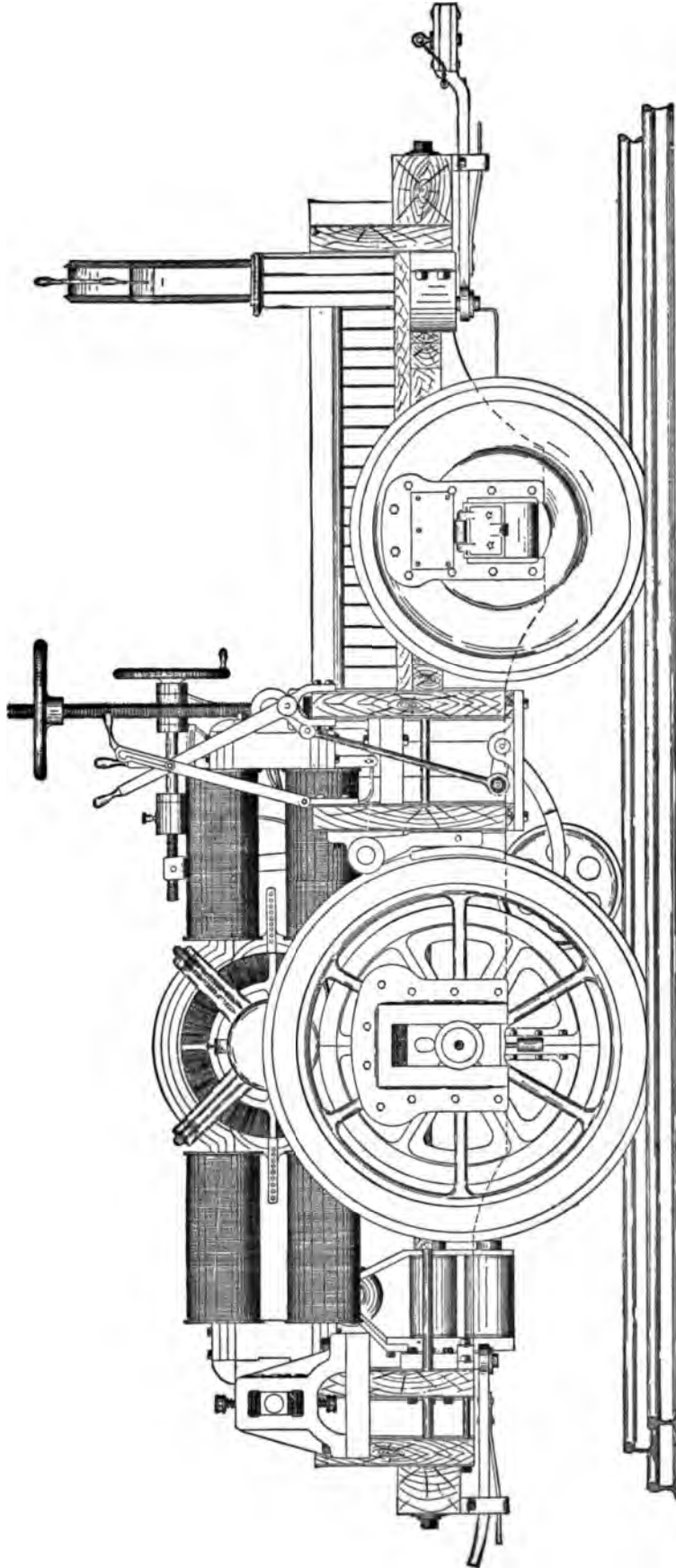


FIG. 81.—SIDE ELEVATION OF DAFT LOCOMOTIVE "BENJAMIN FRANKLIN."

The above represents the cost of his power, and equals the work of thirty horses per day. The average receipts from the cars carried by the two motors are \$18 per day, and he has taken (on a Sunday) total receipts of \$86 in one day.

As the present work goes to press, extensions and improvements are being made on the line. Fig. 80 represents the new overhead conductor attachment which has recently been added to the Daft motors on the Baltimore & Hampden Electric Railroad. As will be seen by reference to the cut, the contact mast is so attached as to be readily operated from the inside by the engineer; this was deemed necessary as the overhead conductors are at present only used at street crossings, thus leaving the track at such places free from the third rail and the raised guard, which were found to be objectionable. The manner of connecting the motors with the overhead conductor for the California railroads, now being equipped by the Daft Company, differs in some respects from that shown in the engraving, especially in the manner of completing the circuit to the motor; but as this plan has not yet been put in operation no further reference need now be made to it. As an instance of the continued successful working of the Baltimore road, it is worthy of note that on the three recent holidays, the 3d, 4th, and 5th of July, upward of 7,000 passengers were carried, or over 3,400 more than by horses for the same time last year. From figures supplied by Mr. T. C. Robbins, it appears that the line has carried 31,907 more passengers than it did with horses during

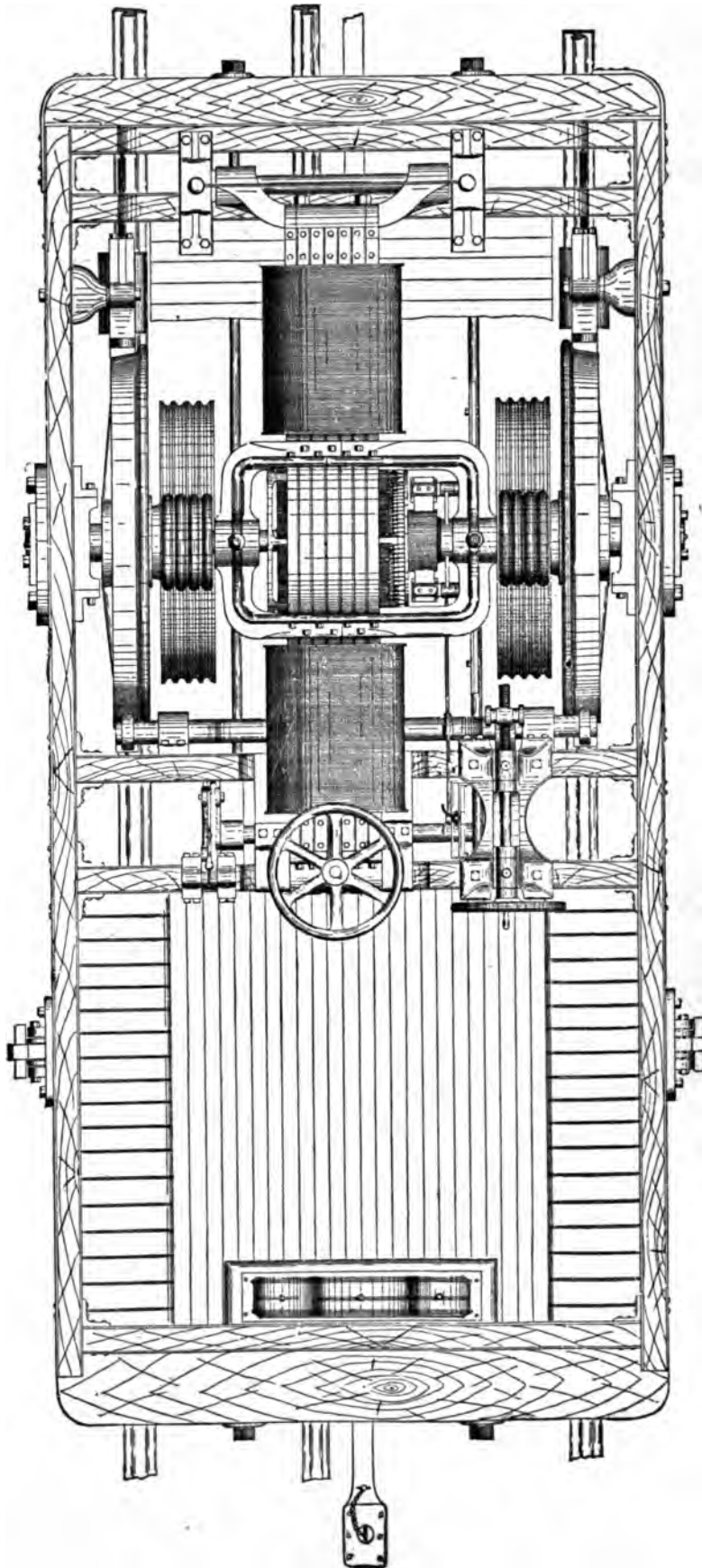
a like period of nine months, and that the cost per passenger has been only 1.66 cents, as compared with 3.01, or .83 cents per passenger mile as compared with 1.55 cents with horses. The cost of horse power per day was \$18; the cost of electric power is \$12.

It may be safely asserted that few engineering events within the last few years have attracted more popular and professional attention than the trials of electricity as a motive power on the elevated railways of this city. The daily papers printed columns regarding the event, and a number of illustrated papers produced illustrations of the Daft motor put upon the tracks.

Before entering into a description of the system, as it is operated, it may be well to recall the events which led up to the present state of affairs.

The idea of running the elevated railway trains by electricity was broached several years ago, the many strong points in its favor, over steam, being pointed out. Nothing, however, was done in the matter beyond its mere discussion, until the early part of 1885, when at a meeting of the various electric motor companies, an attempt was made to consolidate their interests, and to test the motors of the various companies represented. A commission was to be appointed (Sir William Thomson being designated as one of the members) to test the motors, and the best system was to be adopted. Several meetings were held, but the scheme finally fell through. This agitation acted as a stimulus, however, for shortly afterward the Daft Company obtained permission to

FIG. 82.—PLAN OF THE "BENJAMIN FRANKLIN."



equip a section of the Ninth Avenue Elevated Railway on its system, while the Edison-Field interests were assigned to the Second Avenue road.

From that time until August, the Daft Company was busy equipping a central station,

central rail, through which the current is led to the motor, is elevated above the outer ones, resting upon the insulator shown in Fig. 76.

The central station, in which the generating dynamos are placed, is situated in Fifteenth street, a distance of about 250 feet west of the

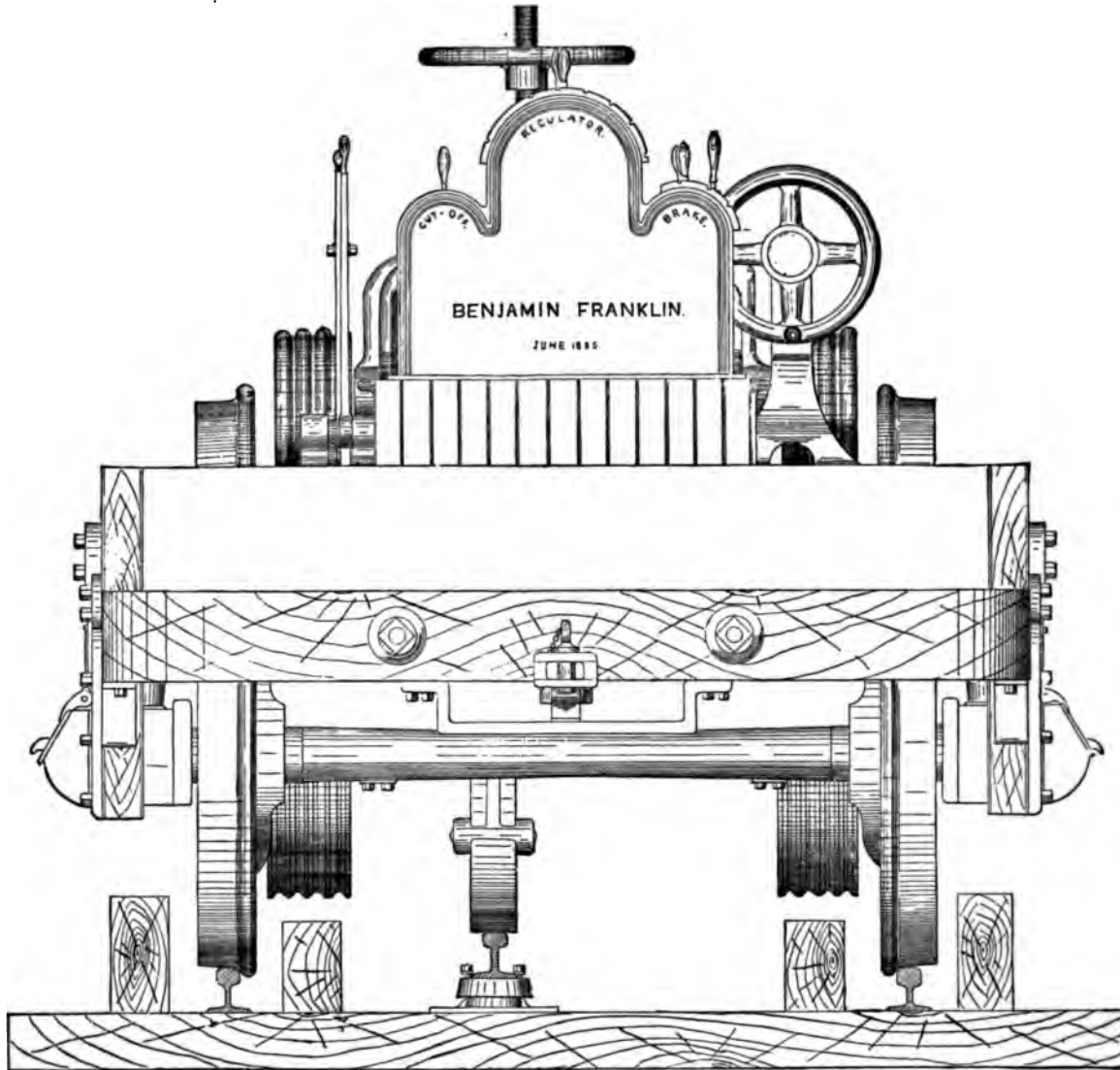


FIG. 83.—REAR ELEVATION OF THE "BENJAMIN FRANKLIN."

building a motor, and laying down the central rail required. It must be understood that the latter operation had to be performed during regular traffic hours, with trains passing every five minutes or less.

The road was and is equipped from the elevated railway station at Fourteenth street, up to Fifty-third street, a distance of two miles, in which a heavy grade is encountered. The

tracks, and connected with the latter by a stout conductor. The station contains a Wright steam engine and three generators. In addition there is a small dynamo which runs the Daft arc lamps, by which the station is lighted at night.

The motor used is named "Benjamin Franklin," with which a speed of twenty miles an hour has been attained.

The illustrations, Figs. 81, 82, and 83, show the arrangements of the motor in detail, as it stood on the track, the cab being removed for the sake of clearness.

In the arrangement of this motor Mr. Daft has entirely avoided the use of belts, power being transmitted by friction from the armature to the drivers, and the amount of it can be regulated at will according to the load. As will be seen from the plan, Fig. 82, the motor-dynamo is supported at the rear on a shaft resting in bearings; its front end is supported by a threaded eye through which passes a long screw, which is turned by a hand wheel, as shown in the side-elevation, Fig. 81. The armature shaft carries a friction wheel nine inches in diameter, which bears upon a larger friction wheel three feet in diameter, keyed to the axle of the main drivers. With this arrangement it is obvious that by turning the large screw the upper friction wheel can be pressed against the lower to any desired degree, thus preventing slip, even with the heaviest loads. By means of the screw also the entire motor-dynamo can be raised clear above the driving wheels, so that the armature can be taken out and inspected with convenience.

The bronze contact-wheel which bears against the central rail is 15 inches in diameter and is raised and locked by the two levers at the side shown in the view, Fig. 81. Another lever on the other side constitutes the "reversing lever," by which the brushes of the dynamo are set so as to give the motor a forward or backward motion. There are two pairs of these brushes and the motion of the lever alternately puts either pair in contact with the commutator. Like all of Mr. Daft's railway motors, this one is provided with his electric brakes. These consist of large electro-magnets which, being energized, are attracted by the wheels and press against them like the ordinary brake. The motor-man occupies the clear space in front of the motor-dynamo, and before him is placed the case containing the regulating, brake, and cut-off switches, as shown in the end view, Fig. 83. The switch at the right controls the brakes and that to the left makes or breaks the current as desired. In the centre is placed the "regulator," by which the speed of the motor can be altered at will. There the terminals of the compound winding of the motor-dynamo are brought, and by moving the lever

to the different notches, the resistance of the field magnets is altered, which changes the speed correspondingly. The driving wheels are 48 inches in diameter; the trailing wheels 36 inches. Their shafts supporting the motor-dynamo rest in specially designed resilient bearings, so as to reduce any shocks to a minimum. The motor is designed for 75 horse power and a normal speed of eighteen miles per hour, with a possible speed of forty miles. The motor complete weighs nine tons, and measures fourteen feet six inches in length, over all.

With the "Benjamin Franklin" several runs were made, to the satisfaction of all apparently, except Mr. Daft himself, who became convinced that the motor was too light for its work, *i. e.*, that its weight was not sufficient to give it a grip upon the track adequate to the load it could pull. This, however, is a defect in the right direction. Mr. Daft, having temporarily withdrawn the locomotive, has now rebuilt it, making it much heavier, and the demonstration on the elevated road will be resumed as this volume goes through the press.

A recent comer in the field, but one whose operations are destined to be of the first importance, is the Bentley-Knight Electric Railway Company, owning and using the patents of Messrs. Edward M. Bentley and Walter H. Knight, whose system was put to initial experiment in August, 1884, on the tracks of the East Cleveland Horse Railway Company, Cleveland, Ohio. The plant consisted as usual of stationary engines and dynamos (Brush). The conductor was placed in a conduit between the rails and running the entire length of the road. The current was taken up by a conductor brush passing through a slot in the conduit and sliding in contact with the conductor there—thus maintaining unbroken connection with the source of power. The road equipped in this way was two miles long, with a branch track, a turnout and two curves of 45 feet radius; and a railroad crossed it at an angle of 45° on the level. Two motors were employed. The line was operated experimentally for a year, and during that period demonstrated the entire feasibility of electric street railways. Our illustrations Figs. 84 and 85 show the cars as they appeared running through Cleveland. In the one instance, the car is ploughing its way through the unusually deep snow of the winter of 1884-5. At no time was the snow deep

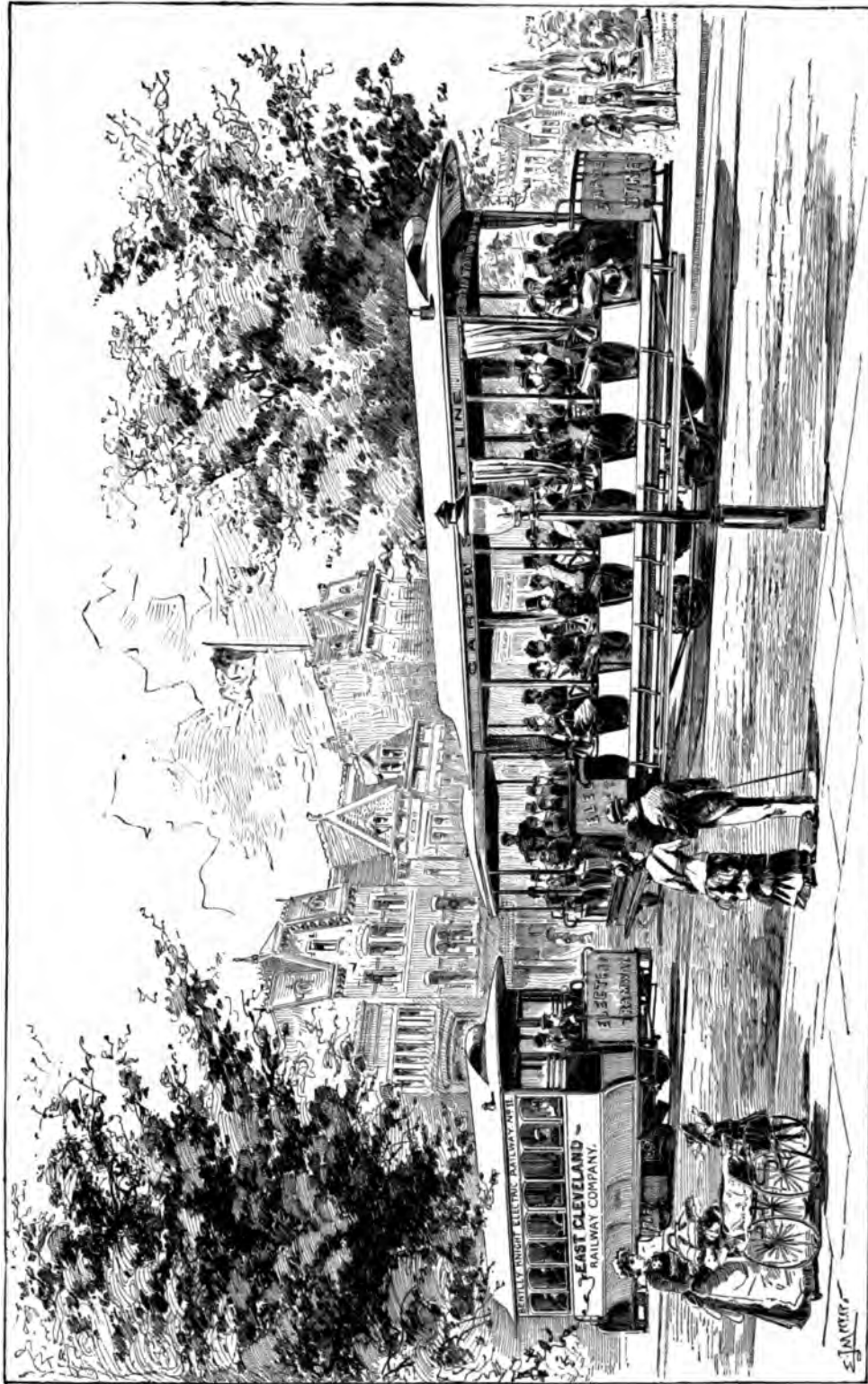


FIG. 84.—SUMMER VIEW ON BENTLEY-KNIGHT ELECTRIC STREET RAILWAY, CLEVELAND, O.

enough to cause any interruption of traffic so far as electricity was concerned. In the other instance, the line is shown under normal summer conditions.

Since that time, the Bentley-Knight Company, having its offices in New York, has made arrangements with the Rhode Island Locomotive Works of Providence, R. I., to manufacture its apparatus, and is now busily engaged making preparations for the work it proposes to undertake. During the past year extraordinary popular interest has been manifested in everything pertaining to increased rapid transit facilities. The extension of the New York and Brooklyn elevated lines, the proposed introduction of the same system throughout our greater cities, and the preliminary work of the several sub-surface railway companies, have stimulated the discussion on the merits of such systems of motive power as may satisfactorily accomplish the work of the steam locomotive without the numerous disadvantages attendant upon its intramural use.

In this connection, the illustration, Fig. 86, of the electric locomotive designed by the Rhode Island Locomotive Works cannot fail to be of interest. This illustration is taken from the working drawings of the Bentley-Knight Company, accompanying various estimates lately submitted by its engineers, Messrs. Bentley and Knight.

This locomotive is especially designed for light passenger work. It is standard gauge, has a wheel-base of twelve feet, and weighs about 48,000 pounds, all of which weight is equally distributed upon its six-coupled sixty-eight inch driving-wheels. The nominal electrical capacity of its twin motors is 500,000 watts. The motor armatures are thirty-six inches in diameter, and exert their force upon the drivers without the intervention of any of the various forms of gearing which some think have seriously impeded the successful introduction of very large electric railway motors. It is equipped with electric headlights, bells, and automatic tubular electro-magnetic brakes, and is fitted with electric connections for incandescent lamps and brakes throughout the train. It has no reciprocating parts, and is equally adapted for use with overhead, surface, or sub-surface connection with the central power station of the line. The company's motors are built so as to be exceedingly power-

ful, solid, and compact, and are balanced to a nicety; and the care with which their interchangeable parts are manufactured renders impossible any serious interruption of work from ordinary accident.

Some noteworthy plans have been prepared by the New York District Railway with a view to the use of electric locomotives, of the kind just described, on the proposed underground railway for Broadway, New York. With such a road Broadway can be utilized for legitimate passenger traffic. It has long suffered, and until recently was suffering, from the diversion of travel to streets parallel with it. The slow and clumsy stages, rattling and jolting over the rough cobble stones, could never accommodate its frequenters satisfactorily. Horse-car lines with which the thoroughfare is now afflicted can never be anything but an impediment to traffic; while they are much too slow to carry the hundreds of thousands of persons to whom, in modern New York, rapid transit between the Battery and the Boulevards has become an absolute necessity. But while horse-car lines along Broadway are a disgrace to the city, the erection of an elevated railroad would be scarcely short of sacrilege. Broadway, with its natural advantages, ought to be the finest street in the world. But that it cannot be if given up to the horse-car or to the abomination of ugliness called an "elevated road." All the requirements of rapid transit for Broadway and of burying the wires are met in the proposed "scientific street." Some objections may already exist, or will perhaps arise when the work of carrying out the scheme is actively prosecuted. But taken in its entirety the idea is one that recommends itself to us as much for its practicability as for its brilliancy. The underground railway would give additional value to property all over Manhattan Island, would relieve the present avenues of traffic that are now so sadly crowded morning and night, would pay handsomely as an investment, and would preserve Broadway in a renovated condition, picturesque and beautiful, for those grandiose demonstrations of a civil and military character in which, as a people, we take so much pleasure. Operated by electricity, after the manner described, the underground road would be very pleasant for travel. Ventilated perfectly, cool, regular, speedy, without noise or dust or smoke, it would compare most favor-

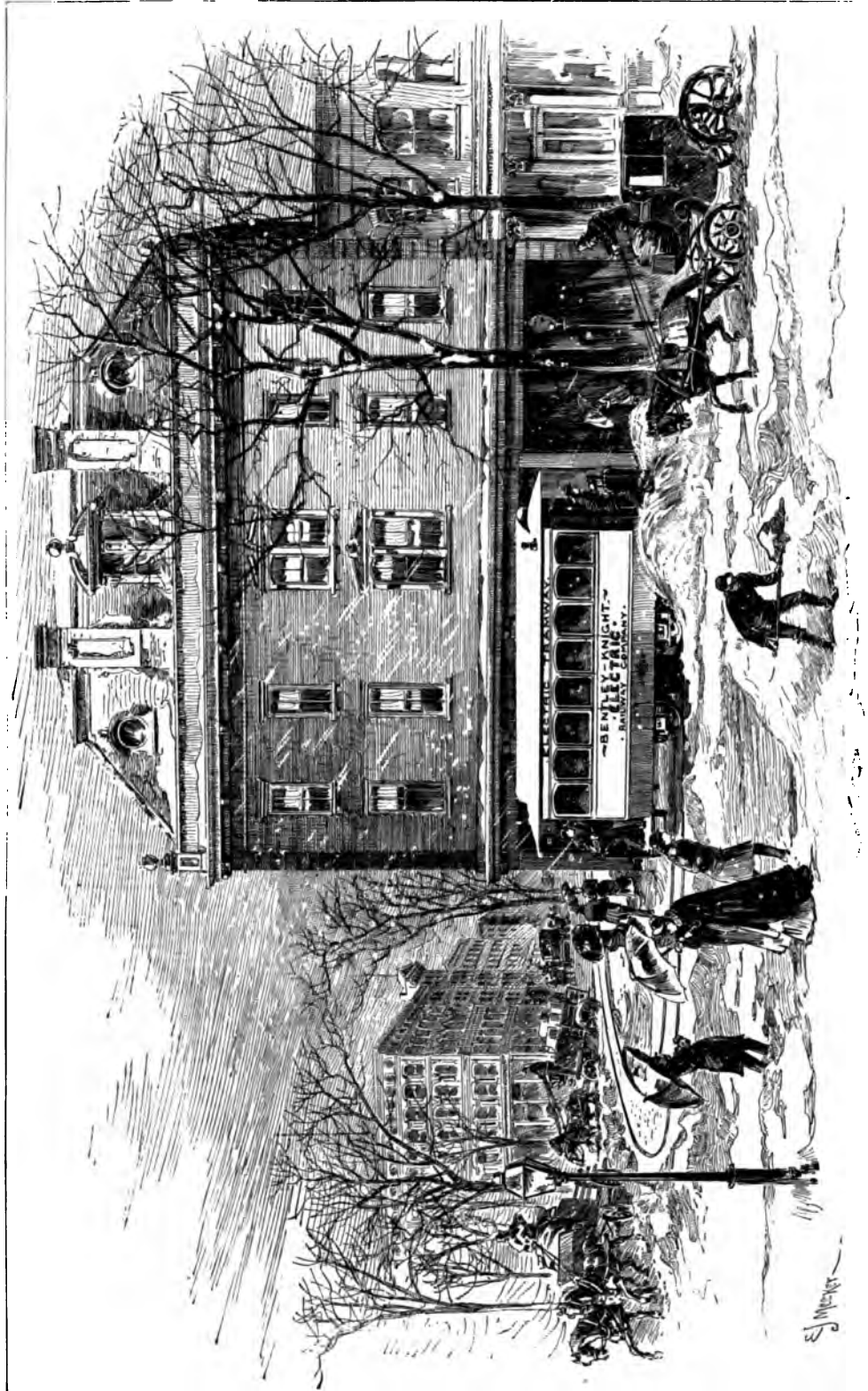


FIG. 85.—WINTER VIEW ON BENTLEY-KNIGHT ELECTRIC STREET RAILWAY CLEVELAND, O.



ably with any other kind of locomotion on the surface or on elevated tracks. It would be a road worthy of Dr. Richardson's ideal City of Hygeia, as well as of the metropolis of the Western Continent.

The main features of the road, as set forth in the carefully prepared plans of the company are the following:

1. Two express tracks, throughout the line from the Battery to the Harlem river, forming a "through," standard-gauge, rapid-transit road of enormous capacity and capable of great speed, with easy access and egress at a few commanding points.

2. Two "way" tracks, throughout the line from the Battery to the Harlem river, forming a rapid-traffic, standard-gauge line between frequent stations.

3. Continuous galleries on either side of the railways, arranged to house all the present water, gas, pneumatic, steam, and other pipes which occupy the street below, together with all the electric cables and wires now arranged upon poles and house-tops above the streets, all service-pipes being in immediate contact with the vault wall of every house on the line, where they will everywhere and at all times be accessible for alteration, repair, replacement, and inspection.

4. The whole to be built and operated (as to the standard section) between the curb-lines and (except at Canal street) above mean high-water, for the purpose of avoiding the invasion of the valuable vaults of Broadway, and for the further purpose of compensating existing vested corporation rights, without encroaching upon vested private rights, or private property.

The roadway of lower Broadway, between the curbs, furnishes all the accommodation required for every purpose. It is divided into two sections; the one centrally placed affords accommodation for the way and express trains; the section on either side disposes of the existing impedimenta of the street at the point of access to the abutting houses. By this disposition of the street all requirements are fulfilled.

- (1) A smooth, noiseless, and unobstructed surface is provided for pedestrian and vehicular traffic.
- (2) Express and way trains for through "rapid transit," and for rapid transit from station to station.
- (3) Permanent housing for sewer, water, gas, steam, pneumatic, and electric conductors and pipes, with access through-

out for inspection, and in all cases in immediate contact with the premises where the connections are to be made. In neither express nor way stations is private property taken, nor at any point does the structure abut private premises, even during construction.

The method of construction is as follows: Street excavation is effected in sections, and is governed by the extent and character of the traffic, travel being maintained unobstructed by a system of movable bridging. A uniform platform of concrete *a*, Fig. 88, about two feet in thickness, floored by a half inch of Trinidad asphalt, extending across the street at a maximum base depth of about seventeen feet, forms a foundation for the whole structure. Upon this is erected the external vault wall *b*, securing to the abutting proprietor the permanent use of the whole vault and area undisturbed throughout the standard section. This vault wall is fitted while under construction with suitable connections for gas, steam, electricity, sewer, and water at every house. This wall is also the external wall of the pipe galleries *c*, arranged adjacent to both curbs. The galleries are subdivided longitudinally and continuously by beams riveted to their internal and inserted in their external walls, which support the sewers and other pipes. Access throughout is provided at the termini and stations, and they are calculated for access to, housing, and inspection of, the tubes, pipes, and wires. The electrical conductors *d*, of the various telegraph, telephone, lighting, burglar-alarm, messenger, and time companies are arranged anti-inductively, upon shelves riveted to the roof and upper gallery beams. There being no permanent floor above the foundation, the pipes in either gallery are accessible from above or below. Street opening for repair, replacement, or connection is thus wholly obviated. The internal wall supporting the galleries is formed by iron columns *e*, placed four feet apart, and coincident with those forming the outer wall of the "way" railways. These columns are composed of two angle irons riveted, and rest upon a continuous granite foundation *f*. The galleries contribute largely to the cost of construction, but are indispensable to a safe, convenient, and equitable replacement of present impedimenta enjoying vested rights, and to access thereto at every house on the route. The space remaining between the pipe galleries is dis-

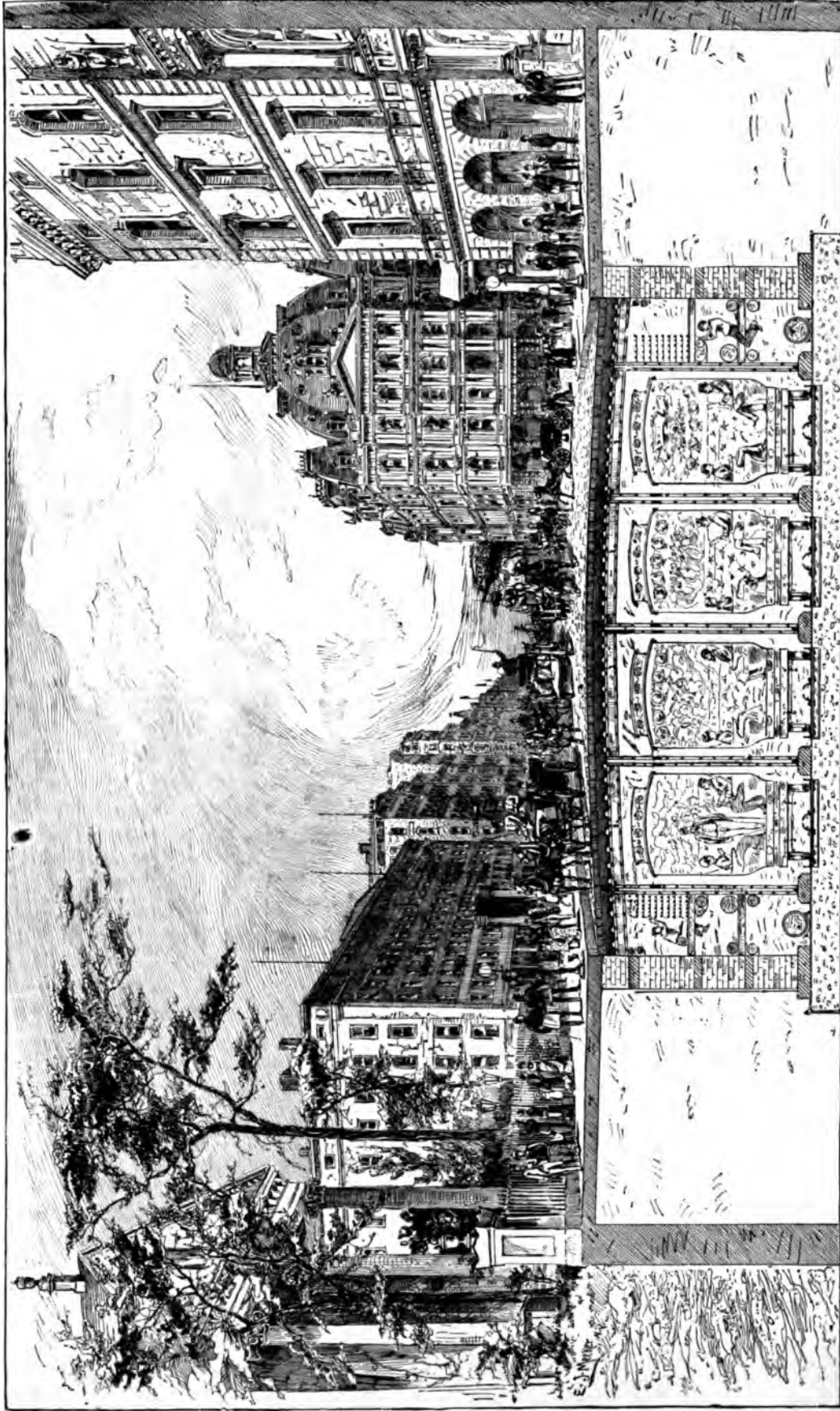


Fig. 87.—STANDARD SECTION OF THE PROPOSED UNDERGROUND ELECTRIC RAILWAY FOR NEW YORK.

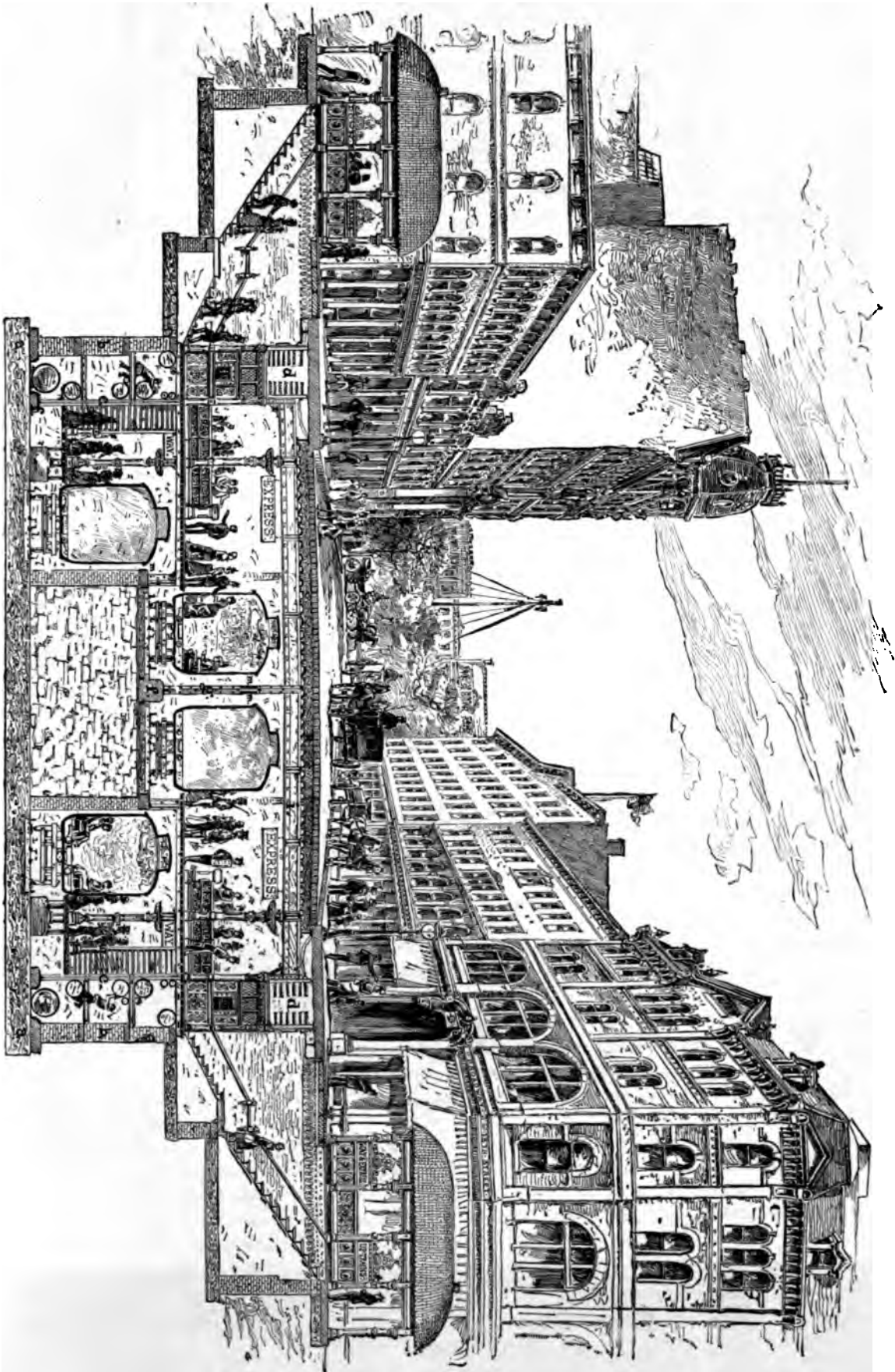


FIG. 88.—STATION NEAR FOURTEENTH STREET ON PROPOSED UNDERGROUND ELECTRIC RAILWAY FOR NEW YORK.

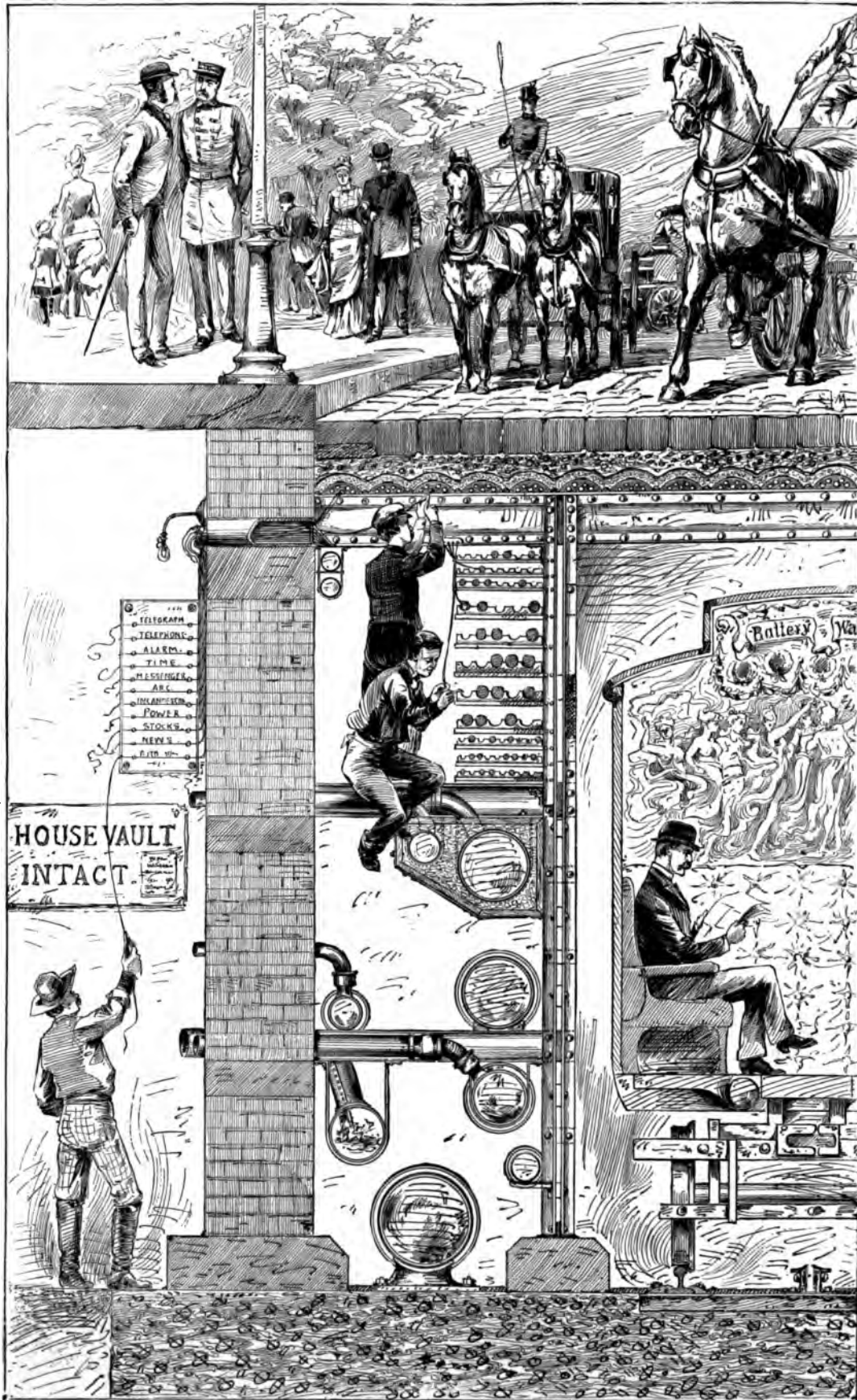


Fig. 89.—METHOD OF MAKING PIPE AND WIRE CONNECTIONS.

posed in four railways, for the accommodation of an up-way and express and a down-way and express train *g*. These ways are formed by five rows of columns, each composed of four angle irons, arranged longitudinally four feet apart, resting on a continuous granite base, the spaces between the columns at the foundation and the roof being filled by a panel composed of a tough, non-resonant material, "ferflax" *h*, composed of steel wire, vegetable fibre, and solidified oil compressed into a solid panel by

the permanent street, upon which the pavement will be relaid. This structure as a whole contemplates the minimum of excavation, the maximum of capacity, the greatest number and most equal distribution of points of support, and consequent maximum of strength and stiffness in use.

The railways form open cylinders from station to station, and the trains being of approximate cross-section constitute loose pistons always moving in the same direction; the ob-

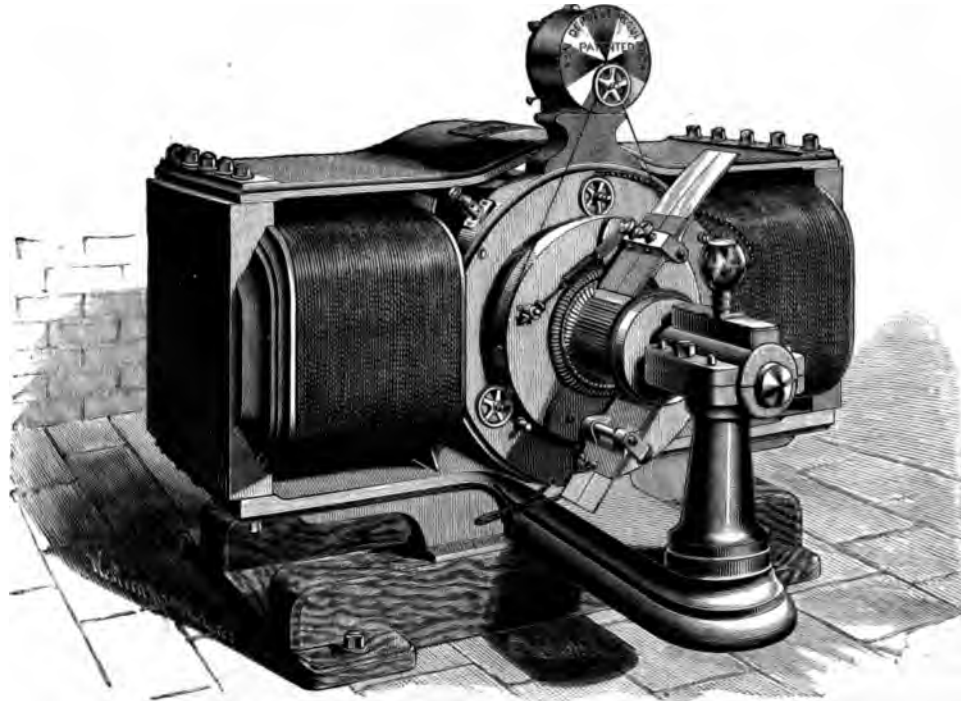


FIG. 90.—VAN DEPOELE GENERATOR.

hydraulic power. This panel fulfils a double function: it completes the enclosure for purposes of ventilation, and it prevents resonance, which might be caused by the rapid passage of a train through an enclosure with metallic walls. The roof is supported and the whole structure tied by beams *i* placed four feet from centres which extend across the entire span, bolted at every eight feet to the columns, the ends being inserted in the vault wall. Upon these beams the steel ten-inch span, buckle-plate roof *k* is laid and bolted; over this is a two-inch skin of Trinidad asphalt, as a protector from chemical contact and dampness and as a slight cushion. Above this is placed six inches of concrete, which completes

vious effect is the establishment of a ventilating current, dependent for its force upon the approximation of cross-sections, the speed of the trains, and the integrity of the tunnels; as the products of artificial combustion are excluded from the tunnels, the requirements of ventilation are reduced to a minimum, and perfectly performed. The traffic-rails, the electrical conductor conduit *l*, and the guard-plate are bolted to the same steel tie, which arrangement secures perfect alignment, the tie being permanently set in the concrete foundation. A deflecting-plate *m* attached to the structure at the cornice line and the guard-plate external to the rail render destructive derailment impossible.

Roads and galleries constructed in this way have the incidental advantage of being accessible from one to another at any point and across the whole system, from curb to curb, performing the vital functions of ventilation, and of guaranteeing complete immunity from collision or derailment, without obstructing transverse communication when it is required.

This plan was first brought to the attention of electricians in 1884, when Col. Rowland R. Hazard presented a paper on the subject at a meeting of the American Institute of Electrical

The Van Depoele electric railway system, now in successful operation at so many places in this country, as well as in Canada, is the invention of Mr. Charles J. Van Depoele, the electrician of the Van Depoele Electric Manufacturing Company, of Chicago, Illinois, and it is the result of constant experiment in generators, motors, and the transmission of power, beginning in 1874 and running down to the present time.

The generator, Fig. 90, is a model of simplicity. The motor is changed slightly from the ordinary Van Depoele dynamo to adapt it to the work of transmission of power. These machines are of various sizes and styles, from a motor weighing one pound to the eighty horse-power motor weighing eight thousand pounds. The accompanying cut, Fig. 91, illustrates the large motor for running railway trains.

The first railway operated under the Van Depoele system was laid in Chicago in the winter of 1882-3, and the current was conveyed by a wire. In the fall of the same year a car was run at the Industrial Exposition in Chicago from an overhead wire.

In 1884 a train was run at Toronto, Ontario, by the Van Depoele system, using an underground conduit. This road was operated successfully and carried the passengers from the street car line to the exposition grounds, and was a perfect success. It was operated as long as the exposition lasted. This train averaged 200 passengers per trip; the speed was about thirty miles per hour.

In the fall of 1885, at Toronto, the road connecting the exposition grounds with the street railway, a distance of one mile, was equipped with a Van Depoele motor, Fig. 92. This train consisted of three cars and a motor-car. As there was only one track, it was necessary to run at a high rate of speed. An overhead wire was used as a conductor, it requiring but a few days to put it in operation; an ordinary forty-light dynamo was used, driven by a Doty 10 x 16 engine.

The average speed of the train was about thirty miles per hour. The trains carried from 225 to 250 people, and the average number of passengers per day was over 10,000. The amount of coal consumed was 1,000 pounds per day. This road carried all the passengers that could be gotten on and off the cars.

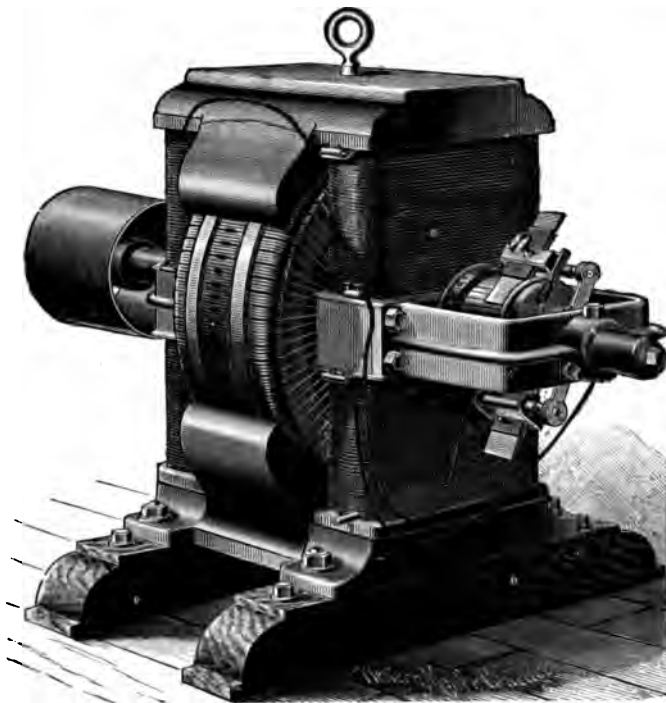


FIG. 91.—LARGE VAN DEPOELE MOTOR.

Engineers; and it is now familiar to the public. Fig. 87 shows a standard section of the line on the Broadway division. Fig. 88 is a view of the road at the proposed station near Fourteenth street and Union Square. Fig. 89 gives an illustration of the method of making connections in the pipe and wire galleries for mains and way service of every description.

The Arcade Railway Company, also proposing to construct an underground railway along Broadway, announces, too, its intention to use electricity for locomotive purposes. The work, whenever carried out, and by whomsoever, will be one of great profit, utility, and convenience.

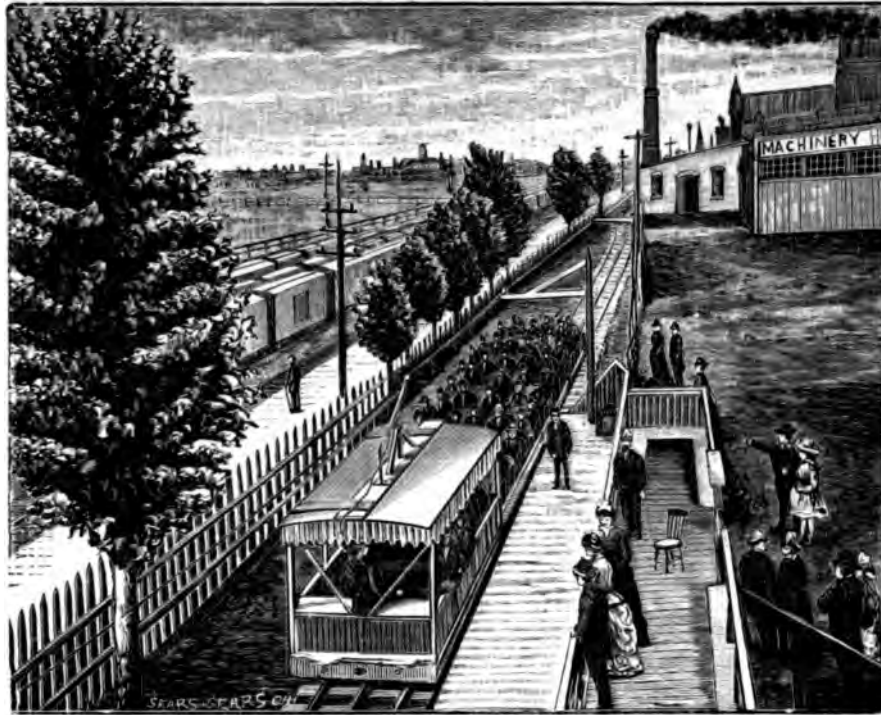


FIG. 92.—VAN DEPOELE ELECTRIC RAILWAY, TORONTO, CAN.



FIG. 93.—MINNEAPOLIS RAILWAY—VAN DEPOELE SYSTEM.



FIG. 94.—ELECTRIC STREET RAILWAY, MONTGOMERY, ALA.—VAN DEPOELE SYSTEM.

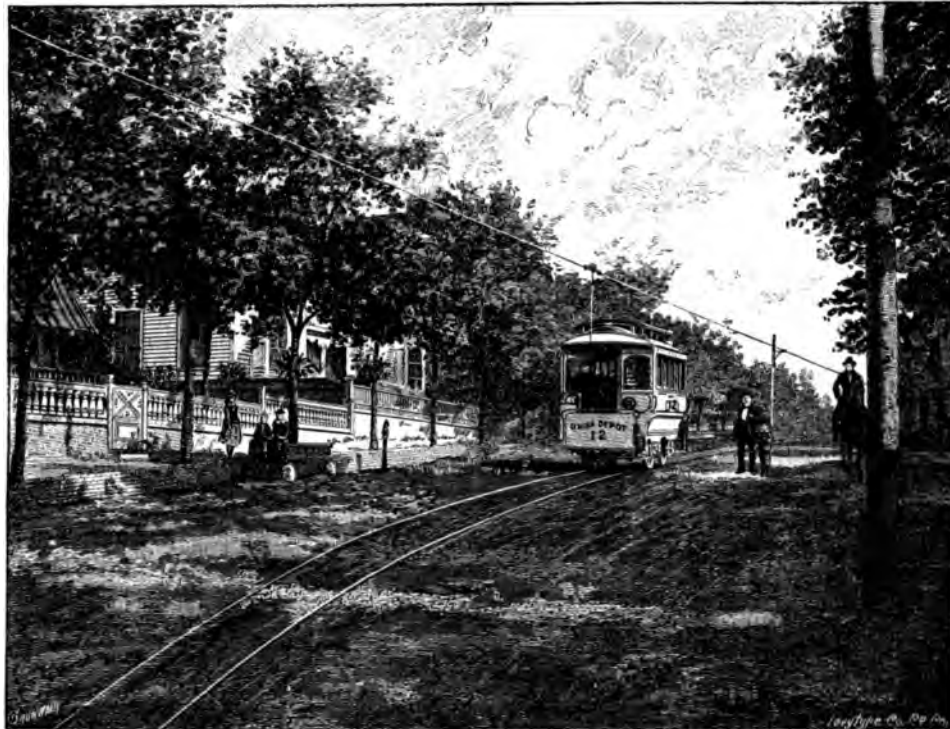


FIG. 95.—ELECTRIC STREET RAILWAY, MONTGOMERY, ALA.—VAN DEPOELE SYSTEM.

For the purpose of conducting experiments, a portion of the South Bend Railway line was equipped in the fall of 1885 and several independent cars were run with small motors, the generator being driven by water-power. It was a distinct success, the cars travelling in different quite a distance from the track, and is driven by an old slide-valve engine, 12 x 18 cylinder, making 125 revolutions per minute. The consumption of coal is about 3,000 pounds for seventeen hours' run. Forty-eight trains are run each way daily, running from 6 A. M. to

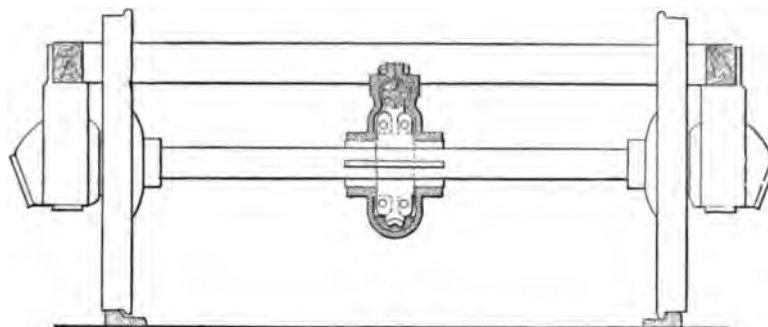


FIG. 96.—PENDLETON METHOD OF ATTACHING MOTORS TO CARS.

directions from the same conductor. This road has not yet been equipped, however, owing to change in management.

At New Orleans, during the late exposition, a train, consisting of three large cars, was run successfully until the end of the exposition.

The Minneapolis, Lyndale & Minnetonka Railway Company, of Minneapolis, have been obliged to discontinue the running of their loco-

11.30 P. M. Trains are composed of from three to four closed railway coaches weighing eleven tons each, or of a larger number of open cars weighing six tons each. As many as eight of these cars have been hauled at one time, and this up a grade of three and one-half per cent., and the cars crowded to their utmost capacity with passengers, giving a total of ninety-one tons. The motor works perfectly.

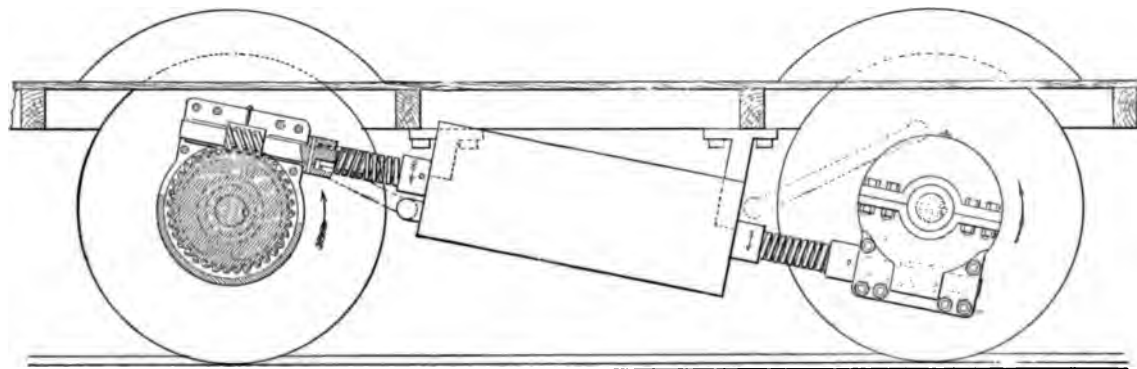


FIG. 97.—PENDLETON METHOD OF ATTACHING MOTORS TO CARS.

motives in the more thickly settled portions of the city of Minneapolis, and an arrangement was made to bring the cars into the city and deliver them back to the steam locomotives. This is being done successfully (Fig. 93). The motor is located upon a cheaply constructed motor-car and takes the current from an overhead copper wire. The generator is placed

At Montgomery, Ala., the Capital City Street Railway have been running two cars for some time (Figs. 94 and 95). The grades are over seven per cent.; the distance is over one and one-half miles. Motors are placed on the platform of each car and do the work well. The speed over the grade is six miles per hour. The cars run sixteen hours per day, and the generator

is driven by an old-fashioned slide-valve engine stationed 250 feet from the boiler. The amount of coal consumed per day is 3,000 pounds, including getting up steam from cold water.

At Windsor, Ontario, a train has been running on the track of the Windsor Electric Street Railway Company since June 6, and giving good satisfaction. The distance travelled is about two miles. Roads equipped with the Van Depoele system have recently gone into operation at Detroit, Mich., Appleton, Wis., and Scranton, Pa.

Acting upon the idea that the development of the electric propulsion of street cars might be greatly advanced by a device to allow of a ready and cheap method of attaching the motors to the existing cars, Mr. John M. Pendleton, of New York, has designed an ingenious plan of attachment for this purpose, which we illustrate in the accompanying engravings, Figs. 96 and 97. These show respectively a front and side elevation of a car equipped with the motor, according to Mr. Pendleton's plan. The general arrangement of wheels and axles, it will be observed, is the same as that of the ordinary horse car.

The electric motor is suspended from the floor of the car, and the revolving armature carries a coiled spring extension at each end, terminating in a worm or screw-pinion wheel, held by journals on each side.

The interposition of the spring presents several advantages, for it not only allows for the distortion of the car with varying loads, or

from other causes, tending to throw the axis of the motor out of line, but in addition the springs relieve the axles of any sudden strain due to rapid starting or stopping of the motor. The retaining links beside the springs allow of torsion, but limit the extension and contraction of the shaft where heavy strains occur, such as on the ascent of heavy grades.

It will be noted that the two axles are differently geared, one having the worm pinion on the top, and the other at the bottom, of the worm wheels, respectively. By this arrangement the thrust on the motor is equalized and friction on the collars is avoided.

The worms are cut with a coarse pitch so as to allow free movement of the car; but the speed is reduced by the worm wheels attached to the axles, in the ratio of 12 to 1, enabling the motor to operate at the rate of 1,000 revolutions, corresponding to a speed of eight miles per hour for the car.

With the idea of adapting the system to existing rolling stock, the worm wheels are split and securely bolted to the axles and keyed in addition. The hub of the split worm-wheel carries a cover or box, which is made oil-tight and which surrounds the worms. These boxes are filled with oil, which insures a constant and copious lubrication, reducing the friction and wear to a minimum, and preventing the access of dust to the working parts.

(In a later chapter will be found illustrated descriptions of the Sprague, Henry, and other systems.)

CHAPTER VII.

THE USE OF STORAGE BATTERIES WITH ELECTRIC MOTORS FOR STREET RAILWAYS.

IN the present chapter we take up a method which, although now looked upon with distrust by many, may yet prove to be one of the most feasible means for the propulsion of railway cars. We refer to the employment of accumulators, the stored energy of which, conveyed to a motor in the form of current, sets it in motion, and with it the car. While this mode of propulsion was until lately in the experimental state, the progress made has been such that a satisfactory solution of the problem appears to have been reached; indeed, the immediate future will see cars propelled by the energy derived from accumulators, with success, judged from the standpoint both of convenience and economy.

If we undertake to examine into the merits and demerits of such a system, it is discovered that the main argument brought forward against the use of accumulators for this purpose consists in a demonstration of the large loss of power which a number of transformations entail. That a number of reducing stages have to be gone through, is obvious, for we have: I. The mechanical energy developed by the engine. II. The conversion of mechanical into electrical energy in the dynamo. III. The conversion of electrical into chemical energy in the accumulator. IV. The reconversion of chemical into electrical energy. V. The final transformation of electrical into mechanical work by the motor. Here, it will be seen, four transformations take place which must necessarily result in loss, but it is boldly asserted that by good apparatus and economical management these losses are reduced to a point below that experienced with other systems, and with the gain of many offsetting advantages.

There are two principal methods in competition with electricity to supplant the use of horses on tram lines, and they are steam and

compressed air. In comparing electricity with steam, we find two ways in which the latter can be applied, viz., by steam locomotives direct, and by an endless cable driven by a steam engine. Using locomotives, there is required a separate engine and boiler for each car or train of cars, and a consumption of fuel between six and seven pounds of coal per horse power per hour, which latter figure may be considerably exceeded where frequent stoppages occur; and to this must be added the other expenses incidental to engine-running. With cable transmission, there need be only one large engine using two and one-half pounds of coal per horse power per hour; but the cost of construction of a tunnel for the passage of the cable and of intricate machinery for grades and curves is a large item which must be taken into consideration. With compressed air, the use of separate locomotives is necessary, and while the engine may not use more coal than in the preceding case, the large loss of power due to the wasted heat of compression makes it a matter of doubt whether this system can be economically employed for the purpose, often as it has been attempted. Taking up our original system, all that would be required is a good central engine as in the preceding examples, and a dynamo, while each car would be supplied with a small electro-motor and storage batteries fitted into compartments in the car. Objections have also been raised with respect to the power lost in transporting the dead weight of the accumulators and motor, but even this objection appears to have been greatly lessened, so that, as compared with steam and compressed-air locomotives, the former shows up quite favorably.

These are the conditions, roughly sketched, that enter into the problem, the solution of which lies in the choice between a system requiring a large original outlay of capital and

one in which the cost of power or running expense is the principal item.

Looked at from the standpoint of *convenience* and *applicability*, the propulsion of tram-cars through the medium of accumulators must be conceded to be second to no other. The batteries occupy no valuable space, being stowed under the seats, while the motor can be placed under the car body as shown in our illustra-



FIG. 98.—LOCOMOTIVE DRIVEN BY ACCUMULATORS,
LISIEUX, FRANCE.

tions. Adding to this the absence of smoke, dust, escaping steam and its accompanying noise, it becomes manifest that the points in favor of such a system are of a most decided nature.

While it is hardly probable that the storage battery will supplant the locomotive for heavy and continuous railway traffic, it is evident that such a service is eminently applicable on street car lines within city limits; and from this standpoint we have viewed it here. We now pass on to examine what has been done towards putting the system in a practical shape.

One of the instances in which it has been applied successfully is presented by the arrangement in use at a bleaching establishment at Breuil-en-Auge, near Lisieux, France. Fig. 98 shows a locomotive, the accumulators being carried on a tender which is not shown. The installation is used for the purpose of gathering and folding the sheets of linen which are spread out upon a meadow to bleach. The peculiar nature of the case made the use of accumulators the only method which could be applied. A steam engine was out of the question, since the dust and smoke would injure the linen, while to lead the wires through the tracks laid on a damp meadow might have entailed a large loss of current.

London, Brussels, and Paris have all seen tram-cars run by storage batteries in operation, and Fig. 99 represents a car which for some time ran in Paris. The illustration will give a good idea of the manner of disposal of the accumulators and motor.

Early in 1883 a similar experiment in street car locomotion by storage was made at Kew Bridge, London, on the Acton tramway line. The car used at the Kew Bridge experiment and shown in the accompanying illustration, Fig. 100, was fitted with an accumulator battery consisting of fifty Faure-Sellon-Volckmar cells, each measuring 13 in. by 11 in. by 7 in., and weighing about eighty pounds. The accumulator battery was capable of working a tram-car with its full load for half a day, or in other words seven hours. When charged it contained about 560 ampère-hours, of which 400 were withdrawn with the greatest regard to economy. The accumulators were stored under the seats of the car, and the current was conveyed by insulated wire to a Siemens dynamo machine acting as a motor, and connected with the axle of the wheel. As soon as the communication between the boxes and the machine was effected, the electric current being led into the motor set the armature in revolution, and the power was conveyed to a pulley fastened on the same axle as the armature. The Siemens machine worked most favorably with an electromotive force of 100 volts and a current of sixty ampères, and as 746 watts constitute an electrical horse power, the result was a consumption of eight electrical horse power and a yield on the pulley of five and three-fifths mechanical horse power. The action of the motor

could be reversed at will, and the power increased or diminished as required by adding to or taking from the number of cells composing the accumulator by means of a simple switch; while by breaking the circuit the motive power was stopped, and the brake being then applied the car was almost immediately brought to a stand-still.

At the trial trip several noted electricians were present, and the experiment was pro-

tery and electric motor at the close of 1884, and made a tramway four hundred yards long for the car to run upon. The experimental trials with it were carried on for many months, and the results were extremely satisfactory. The whole series of accumulators in the car weighed only one and one-quarter tons, and the motor, gearing, and accessories weighed about half a ton, bringing the total weight of the motive power to one and three-quarter tons. The car,

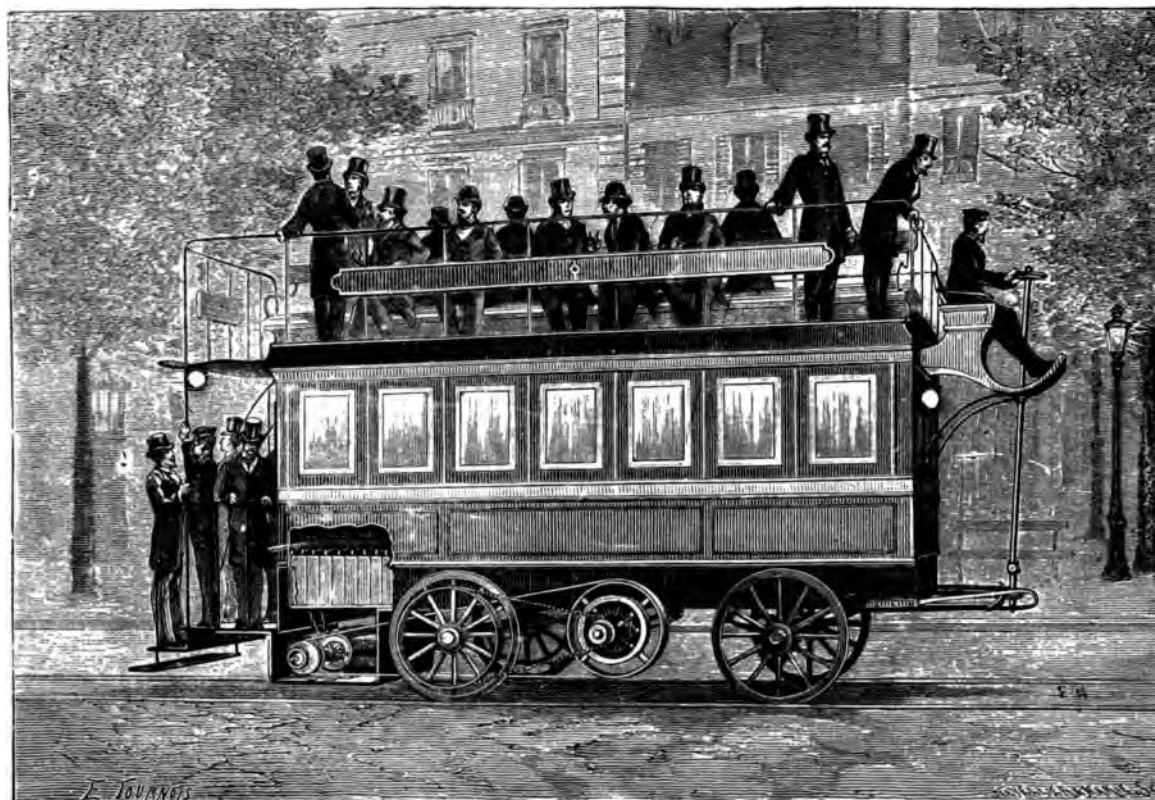


FIG. 99.—CAR USED WITH ACCUMULATORS, PARIS.

nounced by them fairly satisfactory. The car could carry a load of forty-six persons, the total weight being about five tons. The speed attained was six miles per hour, and the car ran smoothly along level road and down hill. The cost of running the car in this manner was estimated at a sum equivalent to \$1.50 per day for each car, against \$6.25 for horses. The car was lighted by Swan incandescent lamps, and furnished with electric bells, all worked from the same accumulators.

Under the direction of their engineer, Mr. Reckenzaun, the Electrical Power and Storage Company, London, fitted up a car with bat-

which had been transformed out of an old one, for many years running on the Greenwich and Westminster line, weighed two and one-half tons—the modern cars on the American lines weigh only thirty-two cwt.—and its load of forty-six passengers brought the total up to five and one-half tons. Comparing the weight of this motive power with steam or compressed-air locomotives, which do not weigh less than from eight to ten tons, the comparison speaks well for electricity. The car, moreover, was put on two bogies, each with four wheels, whereby the wheel base was diminished, and the cars could turn corners and encounter curves of very short

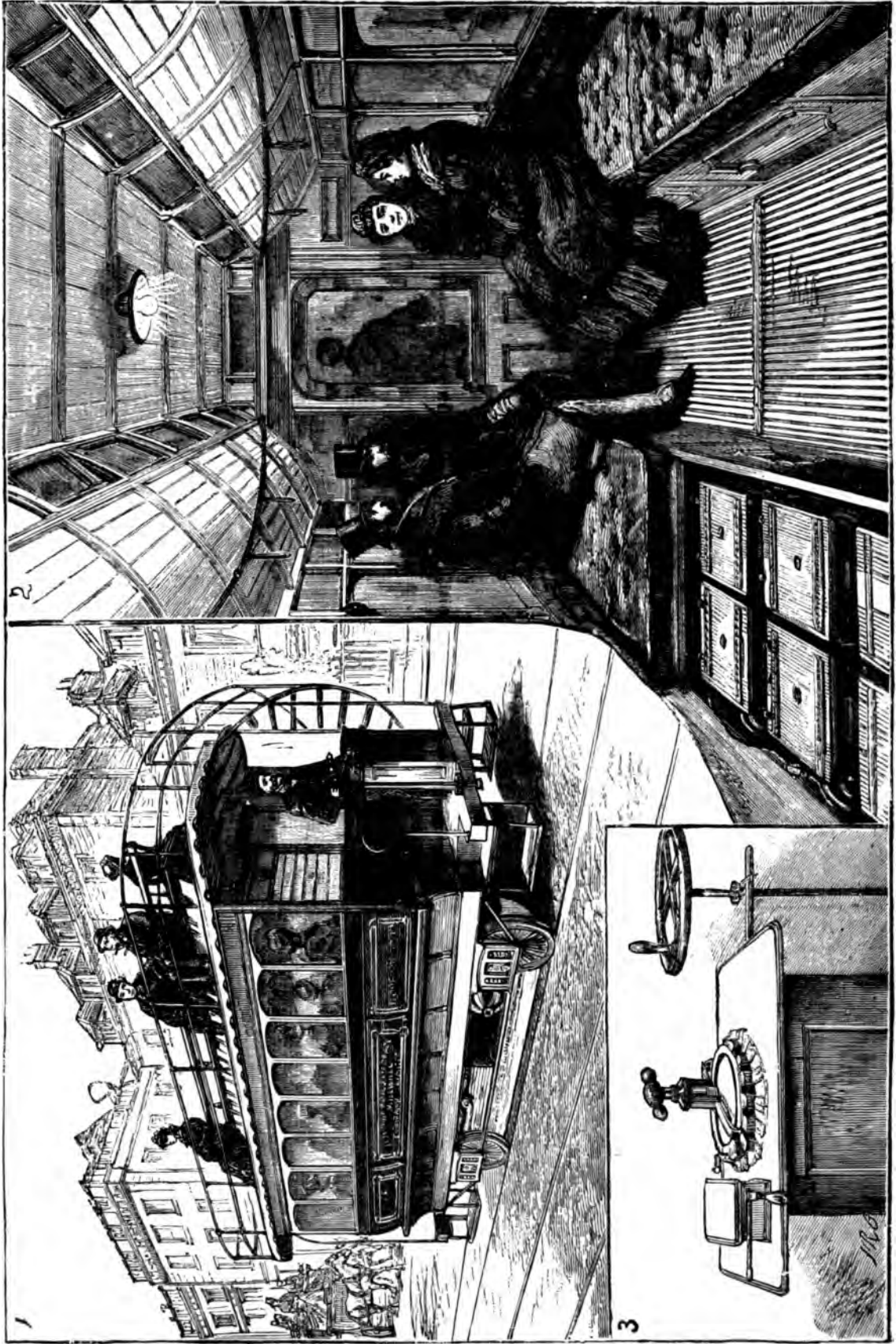


FIG. 100.—THE KEW BRIDGE EXPERIMENTS.

radius. Another advantage of this arrangement was, that there was no such overhanging, and, consequently, no such rocking in travelling, as there is in the ordinary cars which have their four wheels placed at short distances from the centre.

on ordinary street car lines. The car at Millwall could be run for two hours with one charging of the accumulators, starting, stopping, and reversing every minute. The used accumulators were taken out and the car supplied with fresh charged cells in as short a time as is

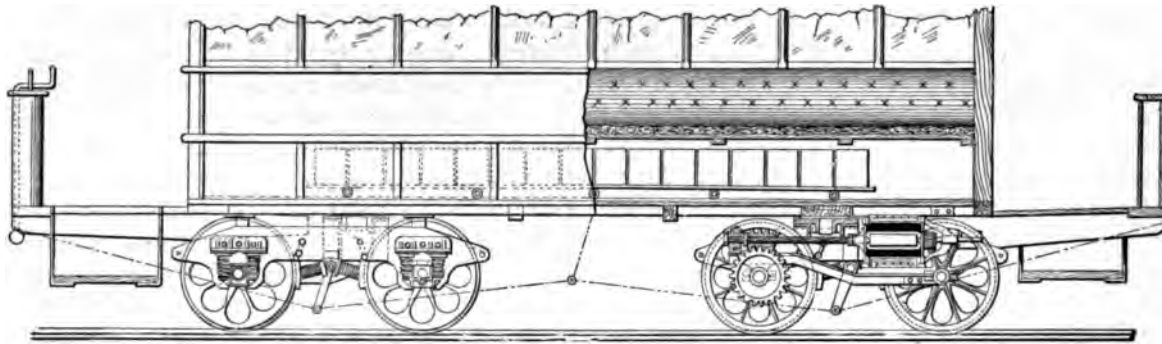


FIG. 101.—RECKENZAUN CAR—ELEVATION.

The next experimental line, at Millwall, was a difficult one. The line made a bend of nearly a right angle, and an actual curve of thirty-three feet radius had to be passed. The inclines varied from a level on the portion from the shed-end to the curve, and rose thence from one in forty to a gradient of one in seventeen at the opposite termination. This steep incline had, consequently, to be faced without a run, a rush being prevented by the sharp curve intervening. The

operation was accomplished with ease by means of a trolley fitted with rollers. The accumulators were placed under the seats completely out of sight; the motor was placed under the car very neatly, and was only seen when looked for. The interior was furnished with four 20-candle power incandescent lights, and with pushes for electric bells for communication between the passengers and the conductor. The travelling

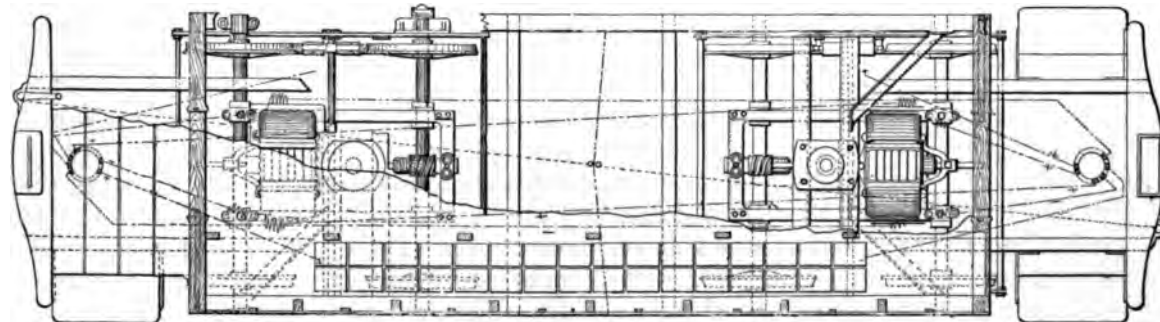


FIG. 102.—RECKENZAUN CAR—PLAN.

new car overcame all these difficulties and made its way with surprising speed and steadiness. It has been considered very adverse to the economical use of stored electricity that so many transformations of energy had to be encountered, but the practical experience of the Millwall experiments was asserted to be that the running expenses, including fifteen per cent. for depreciation of machinery, and fifty per cent. on accumulators, were about half the cost of horses

was perfectly free from vibration or tremor of any kind, and was absolutely faultless in that respect. Every detail, mechanical or electrical, had been well thought of and well worked out.

Within the last few months, Mr. Reckenzaun has made again a highly successful demonstration—this time at Berlin—with his motor applied to street cars and deriving current from storage batteries. Our illustrations, Figs. 101 and 102, show the car, in part sectional elevation

and in plan, and give the general arrangements which have been worked out with great care and do credit to Mr. Reckenzaun's perseverance and skill. The various arrangements may be classed under the following headings, viz.: 1. The battery. 2. The motors. 3. Reversing and transmitting gear. 4. Speed regulation. 5. The brakes.

1. The battery consists of sixty cells, each weighing forty pounds and with a capacity of 150 ampère-hours. They are placed on a board under the seats of the car, resting on rollers, so that they can be readily run in and out. There are two rows of fifteen cells each under each seat. They are coupled in series, and hence give an electromotive force of from 110 to 120 volts.

The storage batteries are changed every two or four hours, according to the length of the trip, and the change can be performed in about three minutes, not occupying more time than a change of horses.

2. The electric motors employed are of the Reckenzaun model. They weigh 420 pounds, and are capable of delivering from four to nine horse power. At 120 volts their efficiency is seventy-five per cent., and at the nominal speed of seven miles per hour they make 1,000 revolutions per minute. But this speed can be raised to ten miles per hour.

3. The reversing arrangement by which the car is run in either direction consists, as in many electric railways, of two pairs of brushes, either one of which is brought in contact with the commutator, according to the desired direction. For this manipulation of the brushes a lever similar to the reversing lever of a locomotive is employed.

The car body, as will be seen, is mounted upon two trucks, each of which carries a motor; and worm gearing is employed to transmit power from the armature shaft to the axles of the wheels. Objections have been raised against this form of gearing, on account of the high friction encountered, but Mr. Reckenzaun's experiments show that only fifteen per cent. is lost in transmission. He has also demonstrated, contrary to the general opinion, that the car runs freely on a down grade, its progress not being impeded by the worm and worm wheel. It was, of course, necessary to select a particular pitch of the screw worm to make this possible, and also to insure excellent lubrication.

4. Changes in speed are effected by different combinations between the whole battery and the two motors. In the electrical car tested at the Antwerp Exhibition, and of which an interesting account will be found a few pages later, the same thing was accomplished by a change of potential, effected by cutting out a corresponding number of batteries. This, of course, prevents the batteries from being discharged uniformly, and is not conducive to their long life. Mr. Reckenzaun's method of employing all the batteries during all speeds evidently overcomes this objection and allows of three combinations, viz.: All cells connected with one motor; all the cells connected with the two motors joined in series, or all cells connected with both motors joined in parallel circuit. These three methods of coupling suffice to give the car a speed corresponding to the walk, the trot, and the sharp trot of a horse. The switch which accomplishes these changes is very simple, and the running of the circuits is shown in the plan, Fig. 102.

Two forms of brake can be brought into play on the car; the ordinary mechanical and the electrical brakes. The latter are called into action automatically when the switch cuts off the battery current. The motors are then converted into dynamos which generate a current that is sent into the coils on the brake-shoes, magnetizing them so that they are attracted by, and press against, the wheels. At the same time the resistance encountered by the armature turning in the magnetic field also acts powerfully to retard the speed, and both these acting together bring the car rapidly to a halt.

We may add that Mr. J. Zacharias, the engineer of the company undertaking the experiments, calculated from accepted data that the running of such a tramway by electricity instead of horses would bring about a saving of fifty per cent. in the yearly expenses.

At the Antwerp Exhibition, of 1885, a series of most interesting tests were carried out on tramway motors, as mentioned above, and after four months of trial the first prize was awarded to the electric car driven by accumulators. In a paper read before the Society of Arts, early in the present year, Capt. Douglas Galton, the English juror upon the testing committee, gave a *résumé* of the experiments, which rank among the most interesting and important made on this class of motors. There were five

different motors which entered upon the tests, and they may be divided into two classes as follows: Three were propelled by the direct action of steam, and two were propelled by stored-up force supplied from fixed engines.

Propelled by the Direct Action of Steam.

1. The Krauss locomotive engine separated from the carriage.
2. The Wilkinson locomotive, also separated from carriage.
3. The Rowan engine and carriage combined.

Propelled by Stored-up Force.

4. The Beaumont compressed air engine.
5. The electric carriage.

We give below the principal results in so far as they relate to the electric car, and also the tables of comparison between all the motors.

In the electric tram-car the haulage was effected by means of accumulators. The car was of the ordinary type, with two platforms. It was said to have been running as an ordinary tram-car since 1876. It had been altered in 1884 by raising the body about six inches, so as to lift it clear of the wheels, in order to allow the space under the seats to be available for receiving the accumulators, which consisted of Faure batteries of a modified construction. The accumulators employed were of an improved kind, devised by M. Julien, the under manager of the Compagnie l'Electrique, which undertook the work. The principal modification consists in the substitution, for the lead core of the plates, of one composed of a new unalterable metal. By this change the resistance is considerably diminished, the electromotive force rises to 2.40 volts, the return is greater, the output more constant, and the weight is considerably reduced. The plates being no longer subject to deformation, have the prospect of lasting indefinitely. The accumulators used were constructed in August, 1884.

An experiment was made on October 21, 1884, to ascertain, as a practical question, what was the work absorbed by the Gramme machine in charging the accumulators. The work transmitted from the steam engine was measured every quarter of an hour by a Siemens dynamometer; at the same time the current and the electromotive force given out by the machine, as well as the number of the revolutions it was

making, were noted. It resulted that for a mean development of four mechanical horse power, the dynamometer gave into the accumulators to be stored up 2.28 electrical horse power, or 57 per cent. The intensity varied between 25.03 and 23.51 ampères during the whole time of charging. Of this amount stored up in the accumulators a further loss took place in working the motor; so that from thirty to forty per cent. of the work originally given out by the steam engine must be taken as the utmost useful effect on the rail. It was estimated that to draw the carriage on the level .714 horse power was required, or if a second carriage was attached, .848 horse power would draw the two together. This would mean that, say, two horse power on the fixed engine would be employed to create the electricity for producing the energy required to draw the carriage on the level. The electric tram-car was quite equal in speed to those driven by steam or compressed air, and was characterized by the noiselessness and ease with which it was manipulated.

It should be mentioned that the car was lighted at night by two incandescent lamps, which absorbed 1.5 ampère each; and the brakes also were worked by the accumulators. The weight of the tram-car was 5,654 pounds; the weight of the accumulators was 2,460 pounds; the weight of the machinery, including dynamo, 1,232 pounds. The car contained room for fourteen persons inside and twenty outside.

The original programme of the conditions which were laid down in the invitation to competitors, as those upon which the adjudication of merit would be awarded, contained twenty heads, to each of which a certain value was to be attached; and, in addition to these special heads, there were also to be weighed the following general considerations, viz.: a. The defects or inconveniences established in the course of the trials. b. The necessity or otherwise of turning the motor, or the carriage with motor, at the termini. c. Whether one or two men would be required for the management of the engine.

As regards these preliminary special points, the compressed air motor, as well as the Rowan engine, required to be turned for the return journey, whereas the other motors could run in either direction. In regard to this, the electric car was peculiarly manageable, as it moved in

either direction, and the handle by which it was managed was always in front, close to the brake. The carriage was the only one which was entirely free from the necessity of attending to the fire during the progress of the journey, for even the compressed air engine had its small furnace and boiler for heating the air. Each of the motors under trial was managed by one man.

The several conditions of the programme may be conveniently classified in three groups, under the letters A, B, C. Under the letter A have been classed accessory considerations, such as those of safety and police. These are of special importance in towns. But their relative importance varies somewhat with the habits of the people as well as with the requirements of the authorities; for instance, in one locality or country conditions are not objected to, which in another locality are considered entirely prohibitory. The conditions under this head are:

1. Absence of steam. 2. Absence of smoke and cinders. 3. Absence, more or less complete, of noise. 4. Elegance of aspect. 5. The facility with which the motor can be separated from the carriage itself. 6. Capacity of the brake for acting upon the greatest possible number of wheels of the vehicle or vehicles. 7. The degree to which the outside covering of the motor conceals the machinery from the public, while allowing it to be visible and accessible in all parts to the engineer. 8. Facility of communication between the engineer and the conductor of the train. In deciding upon the relative merits of the several motors, so far as the eight points included under this heading are concerned, it is clear that, except possibly as regards absence of noise, the electrical car surpassed all the others. The compressed air car followed, in its superiority in respect of the first three points, viz., absence of steam, absence of smoke, and absence of noise; but the Rowan was considered superior in respect of the other points included in this class.

Under letter B have been classed the considerations of maintenance and construction. 9. Protection, more or less complete, of the machinery against the action of dust and mud. 10. Regularity and smoothness of motion. 11. Capacity for passing over curves of small radius. 12. The simplest and most rational construction. 13. Facility for inspecting and

cleaning the interior of the boilers. 14. Dead weight of the train compared with the number of seats. 15. Effective power of traction when the carriages are completely full. 16. Rapidity with which the motor can be taken out of the shed and made ready for running. 17. The longest daily service without stops other than those compatible with the requirements of the service. 18. Cost of maintenance per kilometre. (It was assumed, for the purpose of this sub-heading, that the motor or carriage which gave the best results under the conditions relating to paragraphs 9, 10, 12, and 13, would be least costly for repairs.)

As regards the first of these, viz., protection of the machinery against dirt, the machinery of the electrical car had no protection. It was not found in the experiments at Antwerp that inconvenience resulted from this; but it is a question whether in very dusty localities, and especially in a locality where there is metallic dust, the absence of protection might not entail serious difficulties, and even cause the destruction of parts of the machinery.

In respect of the smoothness of motion and facility of passing curves, the cars did not present very material differences, except that the cars in which the motor formed part of the car had the preference.

In the case of simplicity of construction, it is evident that the simplest and most rational construction is that of a car which depends on itself for its movement, which can move in either direction with equal facility, which can be applied to any existing tramway without expense for altering the road, and the use of which will not throw out of employment vehicles already used on the lines; the electric car fulfilled this condition best, as also the condition numbered 13, as it possessed no boiler.

In respect to No. 14, viz., the ratio of the dead weight of the train to passengers, if we assume 154 pounds as the average weight per passenger, the following is the result in respect of the three cars in which the power formed part of the car:

Electric car,	$\frac{9,350 \text{ lbs.}}{154 \times 34} = 1.78.$
Rowan,	$\frac{15,950 \text{ lbs.}}{154 \times 45} = 2.30.$
Compressed air,	$\frac{22,000 \text{ lbs.}}{154 \times 56} = 2.55.$

The detached engine gave, of course, less favorable results under this head.

Under head No. 15 the tractive power of all the motors was sufficient during the trials, but the line was practically level, therefore this question could only be resolved theoretically, so far as these trials were concerned, and the table before given affords all the necessary data for the theoretical calculation.

As regards the rapidity with which the motors could be brought into use from standing empty in the shed, the electric car could receive its accumulators more rapidly than could the boiler be brought into use for heating the exhaust of the compressed air car.

Under letter C are classed considerations of economy in the consumption of materials used for generating the power necessary for working.

for electric lights, as well as for an experimental electric motor which was running on the lines of tramway, but was not brought into competition. Capt. Galton summarized his views as follows:

“The general conclusion to which these experiments lead is that, undoubtedly, if it could certainly be relied upon, the electric car would be the preferable form of tramway motor in towns, because it is simply a self-contained ordinary tram-car, and in a town the service requires a number of separate cars, occupying as small a space each as is compatible with accommodating the passengers, and which follow each other at rapid intervals. But the practicability and the economy of a system of electric tram-cars has yet to be proved; for the experiments at Antwerp, while they show the perfection of the electric car as a means of conveyance, have not yet finally determined all the questions which arise in the consideration of the subject. For instance, with regard to economy, the engine employed to generate the electricity was not in thoroughly good order, and from its being used to do other work than charging the accumulators of the tram-car, the consumption of fuel had to be to some extent estimated. In the next place, the durability of the accumulators is still to be ascertained; upon this much of the economy would depend. And in addition to this question, there is also that of the durability of parts of the machinery if exposed to dust and mud.”

TABLE I.

Description of motor.	Total number of train miles run.	TABLE I.		TABLE II.	
		Total consumption of fuel.	No. of lbs. per train mile.	No. of places indicated on the cars per mile run.	Consumption of fuel.
Electric	2,358.9	Lbs. 14,786	6.16	80,203.5	Lbs. 14,786
Rowan	2,616.9	14,498	5.42	148,399.6	14,498
Wilkinson	2,473.3	22,000	8.82	119,085.1	22,000
Krauss	2,457.8	22,726	9.10	108,983.9	22,726
Compressed air	2,259.1	90,420	39.48	123,189.3	90,420

TABLE III.

Description of motor.	No. of seats per mile run.	TABLE III.		TABLE IV.	
		Consumption of fuel.	No. of lbs. of fuel consumed per seat per mile run.	Total number of miles run.	Total consumption of oil, kerosene, etc.
Electric	61,501.2	Lbs. 14,786	.23	2,358.9	Lbs. 99.0
Rowan	135,928.8	14,498	.10	2,616.9	106.7
Wilkinson	93,965.6	22,000	.23	2,457.8	188.5
Krauss	86,039.9	22,726	.25	2,473.3	255.4
Compressed air	132,732.7	90,420	.66	2,259.1	585.2

As electricity was thus awarded the first prize, we cannot, therefore, complain, but we might show that the conditions were very unfavorable for good results, and this is evident when glancing at the consumption of fuel. We find the electric railway requiring nearly twice as much coal as one of the steam locomotives, and about an equal quantity with another steam motor. The report itself explains how this is to be accounted for—other electrical service being rendered—and we may add that the test, if more minutely carried out, would have shown a far greater efficiency for the electric system than appears from the report. This assertion is based upon several facts. In the first place, the engine which was employed in driving the dynamo which charged the accumulators, was a portable one, the economy of which was not determined. A good stationary engine would in all probability have yielded better results.

As regards the figures in these tables, it is to be observed that the consumption of fuel for the electric car is, to a certain extent, an estimate; because the engine which furnished the electricity to the motor also supplied electricity

Starting with an indifferent engine, the charging dynamo is found to have an efficiency of *only fifty-seven per cent.*, a figure far below that attained every day in practical work by all leading types of American dynamo electric machines. What the efficiency of the motor upon the car was, is not stated, but it is evident that if its efficiency was low, another factor against the system is introduced. If, therefore, the consumption of fuel was high, it cannot be wondered at, as the causes are apparent. It would not be asserting too much to say that with a good engine, dynamo, and motor the coal consumption could have been reduced one-half, so that even in this respect the electric propulsion would be equal, if not superior, to steam direct. What makes this trial all the more interesting is the fact that accumulators have been found to give satisfactory service in a trying position, for none can deny that the constant handling and necessary rough usage are far from conducive to the good standing and long life of the storage battery. It appears from the report that the accumulators employed were constructed in August, 1884. If they were in use all that time and yet gave the service they did during the test, it is again evident that the storage battery has entered upon its commercial sphere of usefulness. Instances of this kind, substantiating the durability of the battery, are cropping up almost daily, and the fact is dawning upon the world that the storage battery is not a name but a reality.

In this connection the work of Mr. A. H. Bauer, of the Electric Storage Company, of Baltimore, deserves notice. During 1885 a very successful experiment was made by him on one of the Daft motor cars, for the purpose of demonstrating the practicability of secondary batteries for street car propulsion. Since then Mr. Bauer has devised a novel system that can be applied to existing cars at a very small expense. An experimental car equipped with the system has been running for some time on an eighth-of-a-mile track at the Viaduct Manufacturing Company's works.

Unlike other experimenters, instead of using light-weight cars for his test, Mr. Bauer has attacked the problem from the opposite side; that is to say, he has begun with larger weights than would appear in practice.

The car used is an old one loaned by the Union Railway Company, is twenty feet in

length and weighs 5,400 pounds. The equipment consists of two beams extending from one axle to the other. These beams carry a motor, the armature shaft being extended and having pinions on each end which mesh into counter gears. The countershaft carries a pinion, which in turn meshes into a gear on the car axle. The motor is wound in three sections in multiple arc, and is connected with a double switch located on the platform for throwing one, two, or three of the sections in circuit with the battery, as desired, depending, of course, upon the amount of power the motor is required to develop.

To accommodate the batteries, which are placed under the seats and are entirely out of sight, the body of the car is raised three inches, so as to bring the wheels below the floor. The batteries are set on trays upon rollers, and when necessary to make changes they can be run out on to platforms through doors in the sides of the car, and freshly charged ones run in. This can be done within the time required to change horses. Access to the motor and gearing is had through a trap-door in the floor, or they can be got at from underneath the car.

The weights of the different parts of the experimental car are as follows :

	Lbs.
Car,	5,400
60 cells battery,	5,400
Motor,	923
Gearing,	900
Total,	12,623
	or about 6½ tons.

In practice the above total weight will be reduced to about 7,500 pounds.

The whole car, internally and externally, has nothing whatever strange in its appearance; it looks indeed similar to an ordinary street car propelled without horses or other visible motive power.

The track is one-eighth of a mile in length, beginning at the car-house at the foot of a one in twenty grade, 200 feet in length, on a curve of forty-five feet radius. As already stated, this car has been running almost daily for about two months. With the exception of a bolt or collar, working loose, not a single fault has developed, the car running smoothly and satisfactorily during every trip.

When running at a speed of six miles per hour, the armature makes 800 revolutions per

minute. With 5,400 pounds of battery the car will continue to run without cessation for six hours at a speed of six miles per hour; or a total of thirty-six miles. Tests have also been made with half horse-power cells having a total

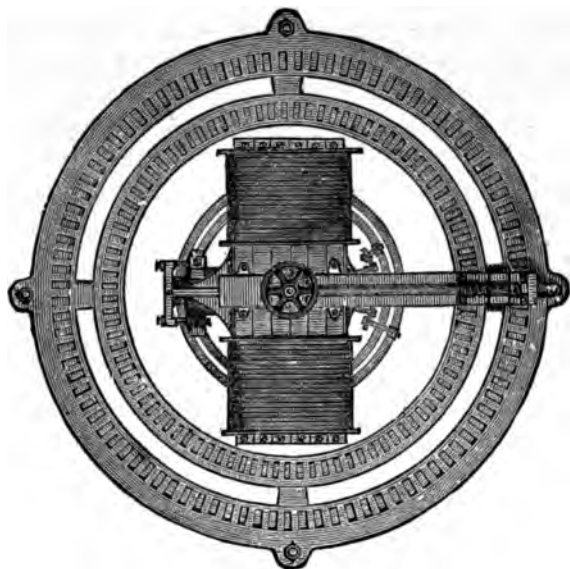


FIG. 103.—GEARING OF ELIESON CAR.

weight of 2,580 pounds, running continuously for three hours, or eighteen miles, before requiring to be changed.

Calculations based on the efficiency of the above-mentioned and other trials, show that the cost of running a line of street cars equipped with the Bauer system should not exceed \$2.21 per car per day. The average cost of horsing is understood to be \$4 per car per day. Given a line running say twenty-four cars it will be seen that by substituting this system or any analogous, a saving of \$1.79 per day per car should be effected. This for twenty-four cars amounts to \$15,680 per annum, a sum that at six per cent. represents the interest on \$261,340.

In Figs. 103, 104, and 105 is illustrated the method of Mr. Elieson, put in operation by the Electric Locomotive and Power Company, London. The novelty in the apparatus consists in the arrangement of the gearing by which the motor can be driven at a very high velocity, and thus work under favorable conditions for economy.

The mechanical connection of the motor is very ingenious. Mr. Elieson has applied a lever between the electro-motor and the axle of

the locomotive in such a way that the motor, which must necessarily run at a high rate of speed in order to develop the greatest efficiency, acts through the lever by a method analogous to the case of a man using a crowbar for the purpose of lifting a heavy weight. By this contrivance the *vis inertia* of the loaded tram-car is easily overcome, and it is evident, even to non-scientific readers, that speed is then easily attained until the natural speed of the electro-motor is approached by the rate of speed of the driving wheels.

Instead of the electro-motor being a fixture, and having motion transmitted from it through belt or crank gearing to the wheels of the car, the motor itself revolves, the motion being transmitted through bevel gearing. It has, as will be seen, Figs. 100 and 101, a vertical shaft through its centre, to which a motion lever projecting horizontally about two feet, and carrying at its outer end a spur-wheel gearing into a fixed circular rack, is secured. This vertical shaft carries at its lower end a bevel wheel, which gears into one or other of two similar wheels on the driving axle of the engine. The mitre gearing is equipped with a mechanical

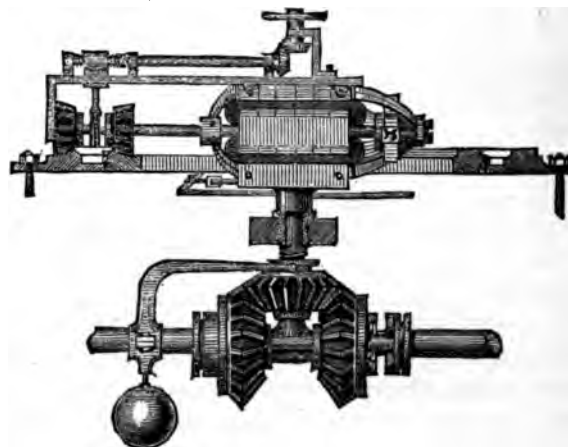


FIG. 104.—GEARING OF ELIESON CAR.

clutch, by means of which the locomotive may be made to run either backward or forward, a lever, acting mechanically, throwing the motor in or out of gear, or adjusting the clutch by a simple movement of the hand. This suggests itself as being a very good arrangement indeed. The electrical details are very simple. The motor is fitted with collecting brushes travelling on two fixed circular rings of copper, separated

from each other by a flange. The speed of the motor is varied by inserting resistances in the ordinary way, and it is evident that great care has been exercised to avoid anything like complexity. The locomotive, Fig. 102, in appearance resembles a small car, and weighs four tons seventeen cwt. The motor, which is of four horse power, consumes about forty ampères per hour, so that it carries power sufficient for six or seven hours of motion, and makes about 600 revolutions per minute when in full swing, or a maximum of 1,000 on a level road. The



FIG. 105.—ELIESON CAR WITH ACCUMULATORS.

speed obtained is eight miles per hour, it being for certain obvious reasons not desirable to exceed this rate. Fifty storage cells are used, giving 280 ampère hours.

Mr. Reckenzaun has recently applied electricity to the haulage of coal in the Trafalgar collieries of Drybrook, Gloucestershire, England, and some recent tests made with the motor are of considerable interest, as they show a remarkable uniformity of action under various loads, together with a high efficiency. A view of the locomotive now in use is given in Fig. 106. The construction of the motor and driving gear is similar to that adopted by the inventor in his electric street cars, but the conditions to be satisfied were widely different from and more difficult than those obtaining in an ordinary tramway. The space is very limited, and since both sharp curves and heavy gradi-

ents occur at frequent intervals, it was somewhat difficult to stow away the necessary power in so limited a space. Within the narrow gauge of 2 feet 7 inches, and an extremely short wheel base, there had to be arranged an electric motor of eight horse power, with suitable gearing, brakes, and attendant details. There is a foot-board which runs all round the locomotive, and there is a brake lever at each end. The box forming the body of the car serves to receive the accumulators, and there is a compound switch at each end by which the motor can be started, stopped, and reversed by the attendant who stands at one end or the other of the foot-board, according to the direction in which the locomotive is travelling. The switches are inclosed in a box to protect them from accidental injury.

At the test, electrical energy was supplied to the motor from a number of "E. P. S." storage cells, and the mechanical work was ascertained by means of a balanced Prony brake. The following table gives the results of the test:

No of test.	Revolutions per minute.	Electrical measurements.		Prony brake.		Electrical energy. Horse power $\frac{E \times C}{746}$	Mechanical work Horse power measured.	Percentage of return.
		Volts.	Current in ampères.	Length of lever in feet.	Weight on scale in lbs.			
1	1,020	105	35.5	2.625	7	4.98	3.568	71.65
2	1,013	107	40.0	"	8	5.73	4.027	70.50
3	982	104.75	39.5	"	8	5.55	3.930	70.8
4	860	95.5	43.25	"	9	5.53	3.870	70.0
5	970	106.5	43.0	"	9	6.11	4.355	71.4
6	900	101.78	46.75	"	10	6.38	4.500	70.5
7	1,022	113.0	47.0	"	10	7.15	4.110	71.4
8	1,018	114.88	47.75	"	10	7.35	5.240	71.3
9	1,047	121.88	53.0	"	12	8.66	6.282	72.5
10	1,070	122.64	54.0	"	12	8.87	6.420	72.3
11	950	113.87	62.0	"	14	9.46	6.650	70.3
12	1,010	127.7	72.0	"	17	12.32	8.85	71.8

In the motor tested there are only two brushes used (one pair), which were not shifted or adjusted during the tests. The motor is so designed that the brushes remain fixed in position, and the direction of rotation of the armature is controlled by merely reversing the direction of the current. Electricity has for some time been successfully applied in these mines for pumping water and for ventilating, and it is now intended to supplant the horses used in the haulage of the coal.

There has now entered upon active duty at Hamburg, Germany, a tram-car which obtains its power from accumulators carried by it. Herr Huber, the engineer in charge, was one of the members of the board which awarded the tram-car run by the Julien accumulators at the Antwerp Exhibition, the first prize, in competition with several other forms of locomotors. He is evidently willing to practise what he believes.

The Hamburg car, which will soon be supplemented by others, weighs, fully equipped,

and can easily be drawn out by opening two long traps in the side of the car. In the car house the vehicle is drawn between two tables, on which the charging takes place, and the accumulators are slid from the car on to the tables. The shunting of the boxes, both in the car and on the charging table, takes place automatically by a contact apparatus, both simple and sure, constructed by Herr Huber.

Four double conductors lead from the accumulators in the car, which are shunted in four groups, to the Julien commutators, of

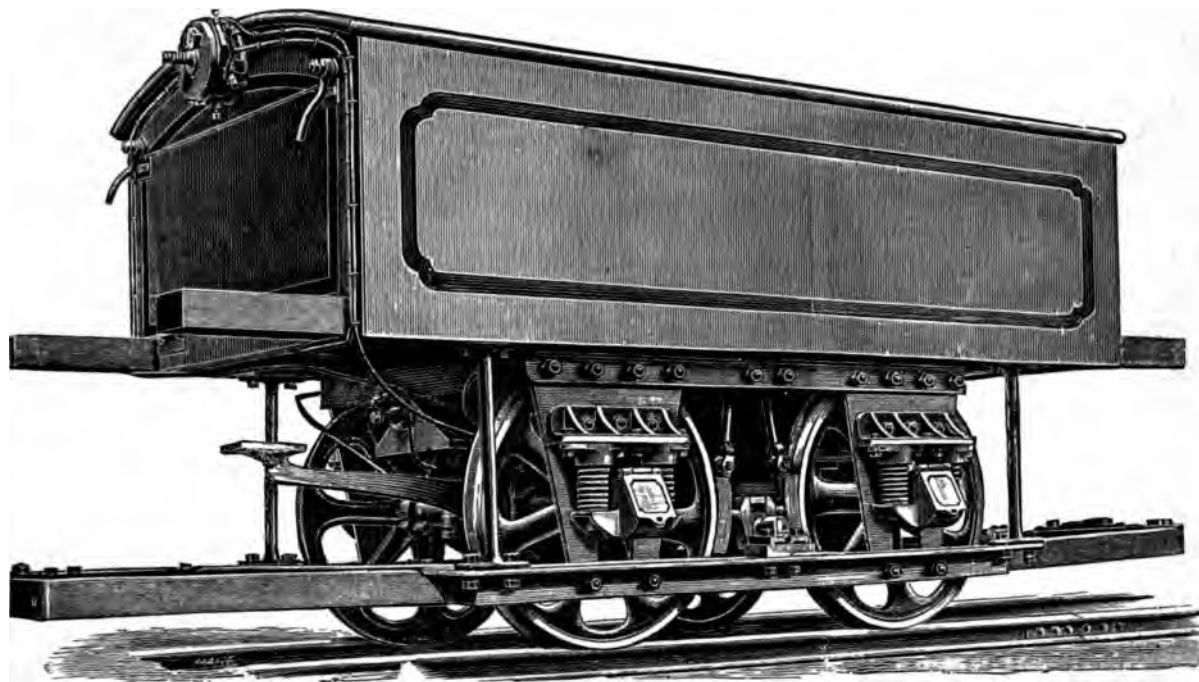


FIG. 106.—RECKENZAUN MINING LOCOMOTIVE.

4,830 kilogrammes. Of this weight, 1,200 kilogrammes is that of the accumulators. The accumulator consists of ninety-six cells, of which every three are united in a single three-cell holder. The cells are formed out of a new material, something like hard gutta percha, but rather more flexible. Each cell contains fifteen plates, seven positive and eight negative. The plates have a surface of only 134 by 147 millimetres, and are about four millimetres thick. The charging requires about eight hours.

The accumulators are distributed in eight low wooden boxes, of which four are stowed away on each side of the car in the space under the seats. The boxes move along greased slides,

which one is placed on each platform. By turning a handle which forms part of the key of the commutator, six different positions can be given to it, viz.:

(1) So that there is no connection between the accumulators and the motor. (2) The four groups of accumulators are connected in parallel arc and placed in connection with the motor. (3) The groups are connected two and two in parallel arc, and the two pairs in series and in connection with motor. (4) Two in parallel arc behind the other two in series. (5) All four groups in series. (6) All four groups in parallel arc, but unconnected with the motor. The commutator stands in this position with the key up during the periods of stoppage.

A great advantage of this arrangement is that different velocities are obtained without the application of any current regulator or resistances.

The positions (2), (3), (4), (5) of the key correspond to the electromotive forces 48, 96, 144,

mits its power by means of hemp cords to a loose axle between the two wheel axles, and from hence the power is given out by means of chains to the wheel axles. The hempen ropes are protected as much as possible against the influences of weather by a special preparation.

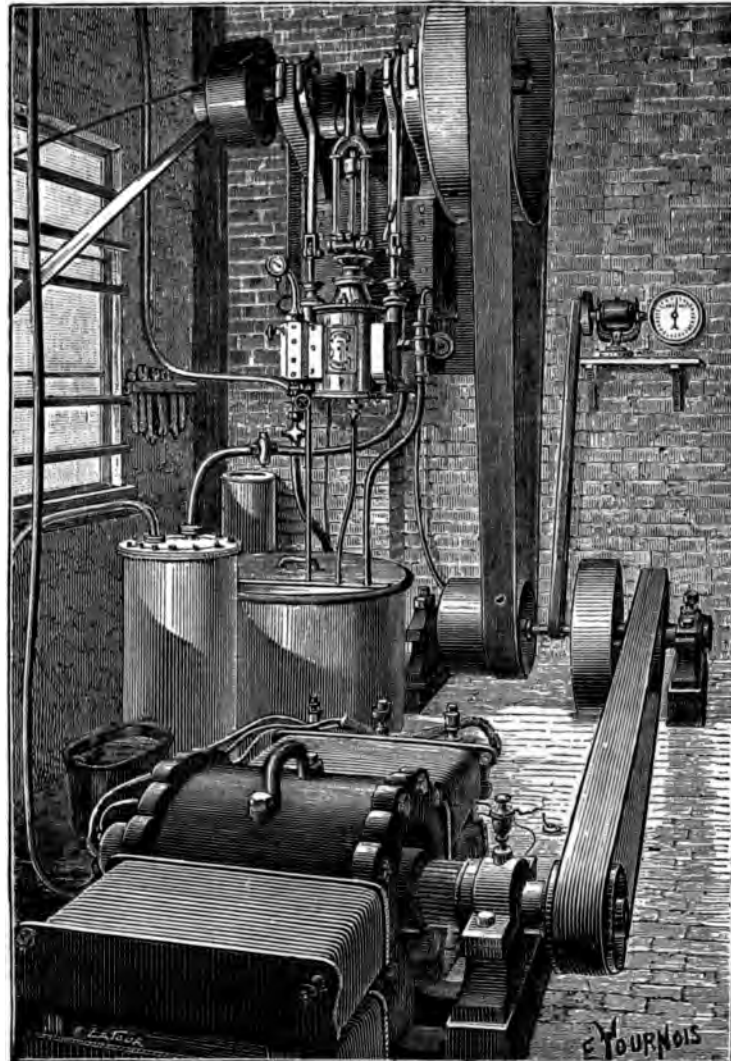


FIG. 107.—CHARGING STATION, HAMBURG ELECTRIC STREET RAILWAY.

and 192 volts on the motor, and its velocity again corresponds to these electromotive forces. The normal current amounts to about eighteen ampères, while on inclines and curves the current may sometimes reach eighty ampères. The motor is a Siemens series machine, model *D*, with about 0.6 ohm resistance. It is hung under the car and trans-

The reversal of the direction of rotation of the machine is brought about by changing the position of the brushes; there are two pairs of brushes about ninety degrees apart, of which only one pair rubs at one time.

One charging is sufficient to drive the car fifty kilometres. Since such a car has to traverse about 100 kilometres daily, one change of the

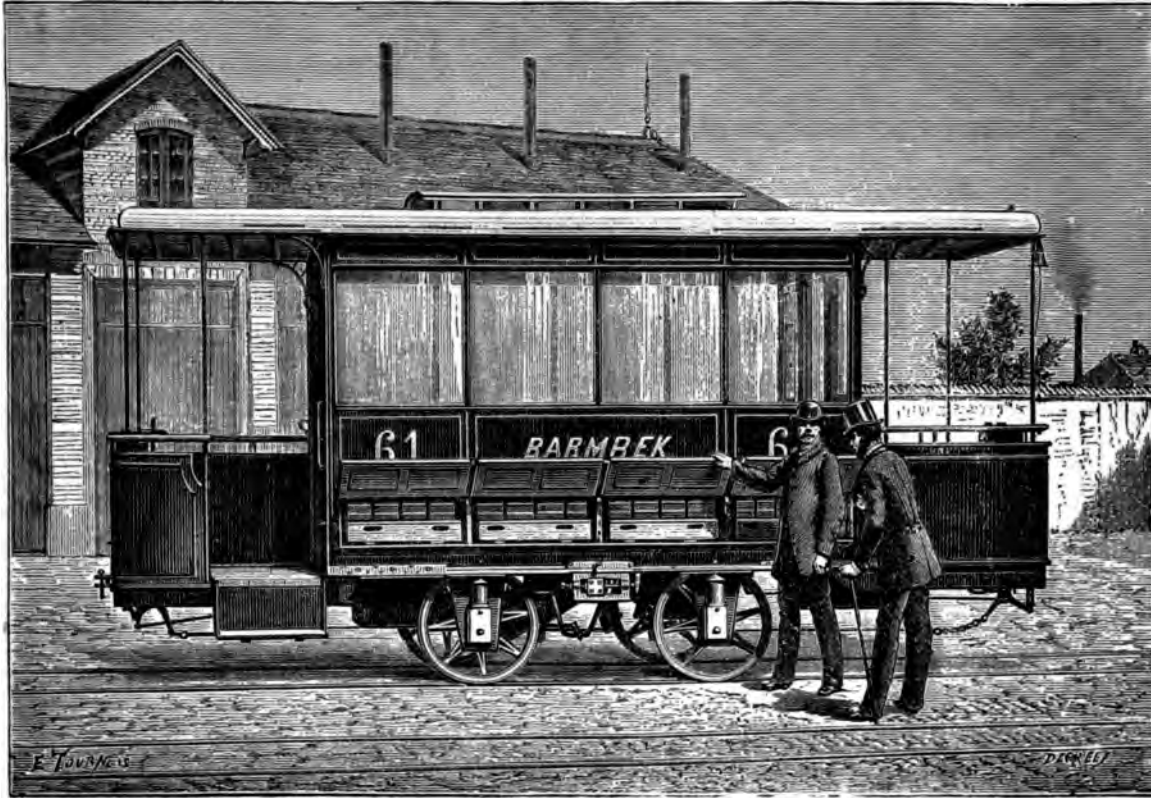


FIG. 108.—CAR, HAMBURG ELECTRIC STREET RAILWAY.

accumulators is enough. Fig. 107 shows the charging station, Fig. 108 the car.

The installation for charging the batteries occupies but a very small space. A small vertical steam engine is mounted on the wall and belts to a countershaft which drives a dynamo

of the Schwerd pattern. In addition, there are a Buss speed indicator and the necessary voltmeters and ammeters.

The use of electric motors with storage batteries, for marine and aerial navigation, is treated in another chapter.

CHAPTER VIII.

THE INDUSTRIAL APPLICATION OF ELECTRIC MOTORS IN EUROPE.

THE Paris Electrical Exposition of 1881 was marked by a revival of interest in electric motors, and many of the new types produced were of great merit, though the rapid advances in this field may have relegated some to obscurity. One of the best known is the machine of M. Paul Jablochkoff, which he calls the "ecliptic," Fig. 109. The construction of the "ecliptic" is

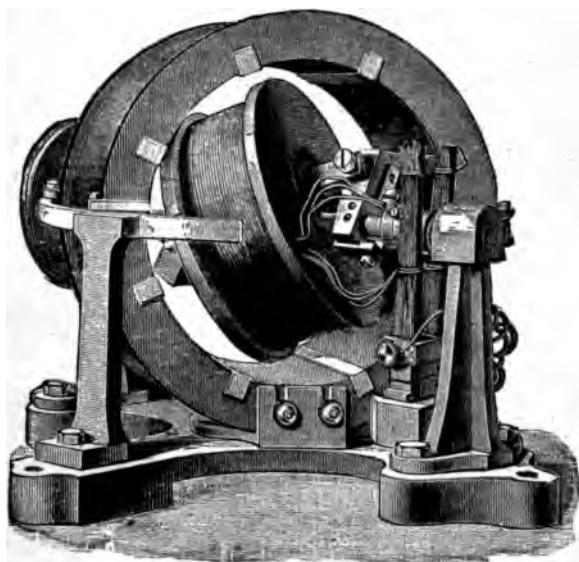


FIG. 109.—JABLOCHKOFF MOTOR.

said to realize an improvement by reducing the mass of magnetic metal which is subjected to changes of polarity, whereby the magnetic inertia is reduced to the lowest possible limit.

This motor is composed essentially of two coils, one of which is stationary and disposed in a vertical plane, while the other is movable and fastened to a horizontal axis in an inclined position. It is from this inclination, resembling that of the ecliptic to the equator, that the name given to the machine by the inventor is derived. The stationary coil, while fixed in

the vertical plane, is not in a plane perpendicular to that of the axis of rotation, but forms with that plane a certain angle, determined by experiment, and which depends on the working conditions of the apparatus.

The stationary coil is wrapped around a copper framework; the movable one is fixed upon an iron core, which, when a current is passed through the coil, becomes an electro-magnet, the poles of which are formed by two circular discs. A commutator is placed on the revolving shaft, against which four brushes bear. This commutator is so arranged that during the revolution of the shaft the movable coil is

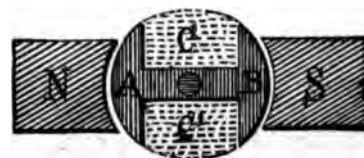


FIG. 110.

traversed by a current always in one direction, and which maintains a constant polarity in the discs of the electro-magnet, but at each half-revolution the current is reversed in the stationary coil, which has no soft iron core.

The motor, then, is operated by the reciprocal attractions and repulsions between a movable, constant electro-magnet, and a fixed solenoid, traversed by currents alternately in opposite directions. These reciprocal actions tend to produce a rotation of the movable electro-magnet placed in the interior of the fixed solenoid. The object of the commutator is to make these actions co-operate in the same direction, thereby producing a continuous movement.

M. Jablochkoff's motor is reversible in the true sense; that is, it can not only convert electricity into mechanical work, but can also convert mechanical work into electricity.

The work of M. Marcel Deprez with electric motors, large and small, has always been full of interest and instruction. Deprez has aimed directly at higher efficiency while avoiding complicated construction. He observed the fact that in ordinary motors of the old Siemens type about one-third of the energy expended is consumed in energizing the magnetic field and in maintaining its power. He therefore con-

ceived the idea of using permanent magnets for the magnetic field. He made comparative tests of two machines, in one of which the field magnets were permanent, and by measuring the power obtained and the amount of zinc consumed in the battery he discovered that the efficiency of the motor having permanent magnets was about sixty per cent. higher than that of the other. M. Deprez found on using this motor as a dynamo-electric machine that its electrical equivalent for the same power, as used on the other machine, was very much higher. He constructed a small generator on

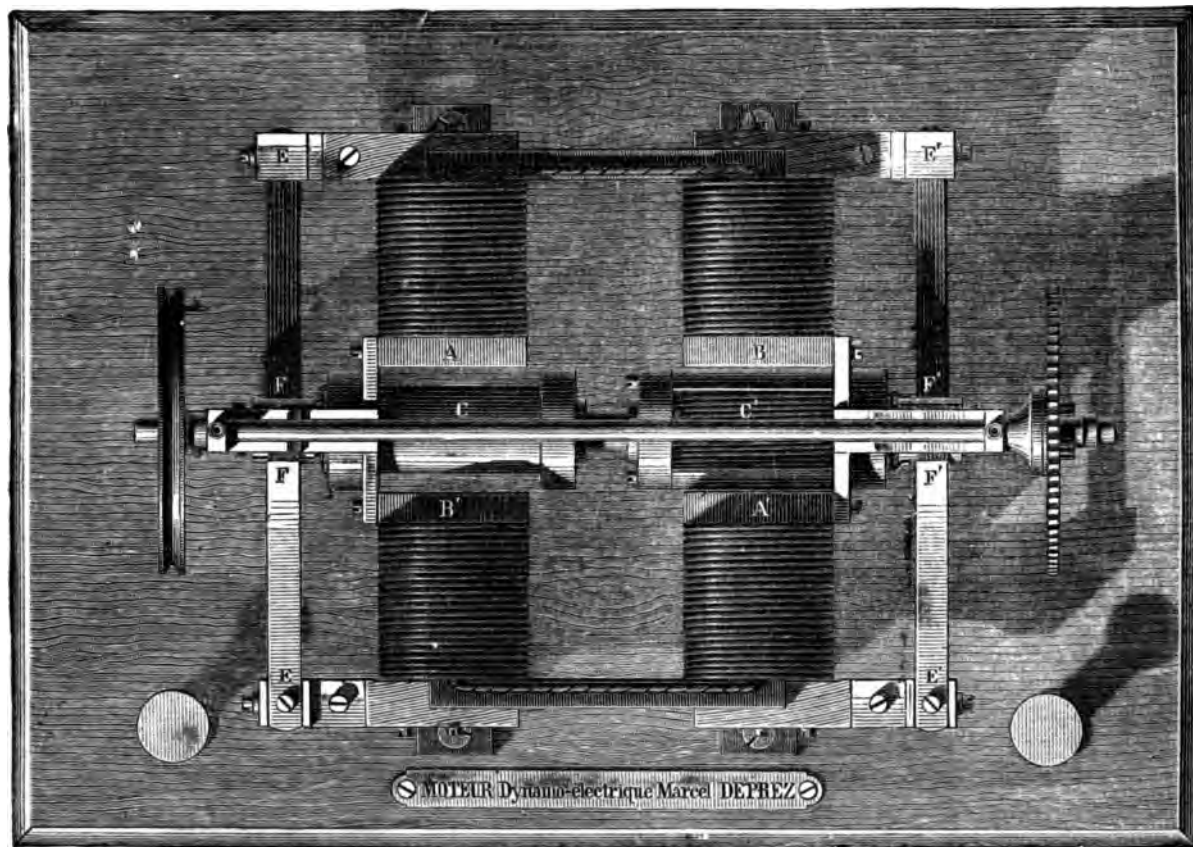


FIG. 111.—DEPREZ'S SMALL MOTOR.

ever. Just as the poles of an armature *A B* (Fig. 110) move into line with the poles of the magnetic field *NS*, the current is reversed in the armature, and instead of attraction repulsion results. Now, if the current in the armature is too powerful, the magnetism of the armature will be sufficient to neutralize the polarity of the permanent magnets, even when the best magnets are used. The result was that, although the efficiency of the motor was very great at first, the power of the motor soon dwindled down by the weakening of the magnet. Another disadvantage of permanent mag-

net. Another disadvantage of permanent mag-

nets was that for the same power they must be much larger than electro-magnets. M. Deprez, therefore, concluded to sacrifice economy in favor of convenience to some extent, and returned to electro-magnets, striving to use them to the best advantage.

Figs. 111 and 112 are *full size* illustrations of a small motor constructed by M. Deprez, which will run a small sewing machine with two Bun-

brushes $E F E' F'$ are supported by small wooden or vulcanite arms attached to the backs of the electro-magnets, which are secured to the base board, as shown, and form the supports for the whole apparatus. These brushes are made long and flexible, so as to provide a light yet smooth and perfect contact with the commutator segments. The speed of the motor is reduced by means of a pinion gearing with a

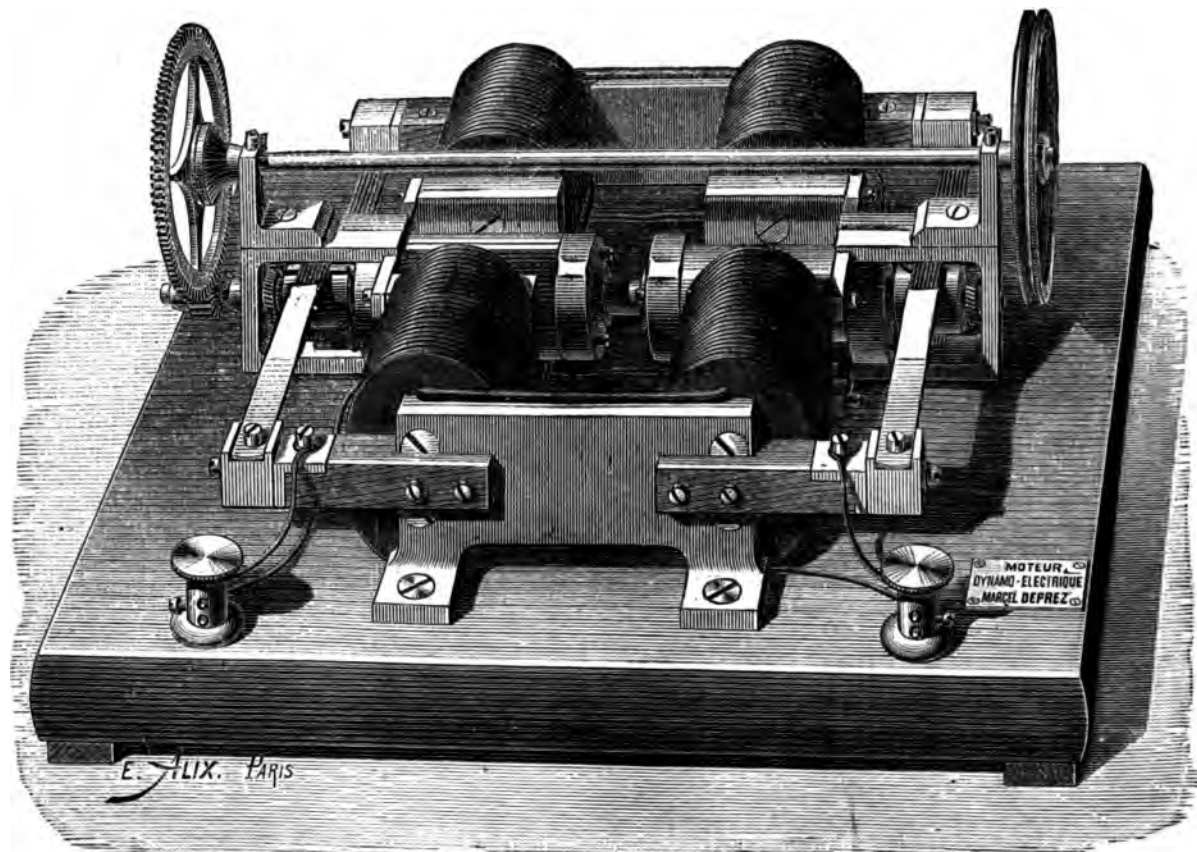


FIG. 112.—DEPREZ'S SMALL MOTOR.

sen cells. Two armatures $C C'$ are mounted on the same shaft, each of which revolves in the magnetic field between the two opposite poles $A B'$ and $B A'$ of two U electro-magnets placed opposite each other. These armatures are sixteen millimetres in diameter and twenty millimetres long, and are fastened to the shaft with their poles at right angles to each other, so that the dead centre of one corresponds to the active period of the other. The poles of the electro-magnets are joined at each side by a brass framework, which extends outward, and has bearings on which the shaft turns, as will be readily understood from the figures. The

toothed wheel which revolves at one-tenth the speed of the pinion.

By changing the connections of the electro-magnets and armatures from series to multiple, three different variations of power may be obtained. The change may be made without trouble. The motor is very compact and light. It has no dead centre and the magnets are disposed so as to secure a powerful magnetic field, which must, of necessity, be exactly equal at both armatures.

The electric motor of M. Estève (Fig. 113) brought before the public in France contemporaneously with that of Deprez, possesses origi-

nal features of great interest. In this motor the ordinary H Siemens armature is materially modified in form, and the magnetic field in which it rotates is also different. In all other small electric motors of this old Siemens type the original H form of armature has always been adhered to with magnetic field pieces of varied form. M. Deprez preferred in his earlier

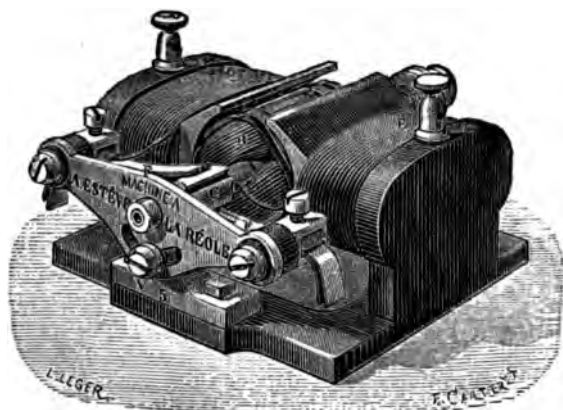


FIG. 113.—ESTÈVE MOTOR.

forms to give to the armature poles *AB* a considerable expansion, and to restrict the field pieces in size, so that they do not surround the armature so completely. This is the disposition adopted in his motor just described, the relative proportion of armature and field-pole expansions being indicated by the section shown in Fig. 114.

In his motor M. Estève evidently follows a different theory, as the magnetic field is expanded so as to surround the armature as completely as in ordinary dynamo-electric machines, while the polar expansions of the armature are entirely suppressed, and it assumes the sectional appearance of the letter *I*, as shown in Fig. 114, which is a sectional plan of this armature and its magnetic field. The armature is, in fact, made of a flat plate of iron revolving on its longer axis, as if the polar expansions of the H armature had been filed down to a level with the central part. The difference will be readily understood on comparing Figs. 110 and 114.

Better results are obtained when the armature core is made up of layers of thin sheet iron separated from each other by means of paper, but M. Estève prefers to make the core with a hollow centre, using insulated plates, which

must be sufficiently thick, otherwise the magnetic reaction of the armature on the magnetic field is lessened materially, just as when no iron cores are used, and the efficiency of the motor is considerably reduced. M. Estève has also tried the use of armature cores constructed of insulated iron wire, but the efficiency obtained was not greater than with the hollow armature just mentioned. He finds that the coercive force of this hollow armature is extremely small, consequently that the polarity may be reversed with extreme rapidity.

The construction of this motor is quite simple and will be readily understood from Fig. 113. The cores of the field magnet are made of cast iron forming one piece with the base, though the winding is more convenient when they are cast separate. The wire is wound on the armature in two equal sections *CC'DD'* (Fig. 114), leaving a small space *EE'* between them. These sections may be connected either in series or in multiple circuit, according to circumstances. The ends go to the two commutator segments *C*, which M. Estève prefers to make of iron. This is a new departure, because the use of copper in commutators has always been regarded as well-nigh indispensable. M. Estève says, in favor of iron commutators, that they wear out much less and do not spark as much as copper ones, while their resistance of contact is not sensibly different. At any rate, he does not find any loss in efficiency in consequence of using them. The brushes *FF* are both held by an oscillating lever, which can be



FIG. 114.

secured at any convenient angle by the set screw *V*, the arrangement being particularly useful in permitting the adjustment of the brushes to the point of least sparking.

The field magnet and the armature are connected in series, and in this condition there is little or no sparking at the brushes, even when using powerful currents. M. Estève experimented with one of his motors placed in a branch circuit from a Gramme machine, and

found that its operation was entirely satisfactory, the motor remaining cool and free from sparks at the commutator. Experiments have also been tried with this motor when its field circuit was derived from the armature circuit, as in "shunt" dynamos, but the results were not as satisfactory.

It is plain that when constructed in this form, the motor is open to the objection of having a dead centre, but M. Estève suggests that by making the magnetic field somewhat wider, two or three armatures may be placed on the same shaft, just as in the Deprez motors.

The design of this little motor both electrically and mechanically is very good, considering the limitations which convenience, cheapness, and durability impose. The form of armature appears to be an improvement in the right direction. It has been shown by M. Trouvé that with the ordinary Siemens H armature the magnetic attraction which causes the rotation is not effective for more than a small portion of the revolution. A little reflection will make this clear. In a motor of this type we have practically two magnets, one of which tends to move constantly so as to place itself axially in the magnetic field of the other with like poles near each other. If the poles of the moving magnet are broad and expanded it does not require to move so much before a certain part of the pole arrives at the axial position. The magnetic attraction becomes concentrated at these points, and there is little or no tendency to the further motion of the armature so as to bring the rest of its mass into the axial magnetic position. The result is that the rotative impulse ceases at a certain distance before the armature reaches the axial position shown in the figure, and the armature must depend on its momentum to carry it as far as the point where the current is reversed and where repulsion will begin. M. Trouvé, in his motors, sought to remedy this difficulty in two ways: First by making the face of the polar expansion of the armature curve on a shorter radius, and second by making the field more open at certain points, or elliptical in shape. The object in either case was to provide for a more gradual approach between the pole of the armature and the iron of the magnetic field poles, so that the motion would not cease until the whole mass of the armature was in the magnetic axis. By these means the efficiency of the motor was

greatly increased and the dead centre, which before that comprised a certain period of the rotation, was now reduced to a mere point.

In the motor of M. Estève the armature necessarily attains the object more readily and surely. It is more certain to reach the position shown in the figure, because no portion of it reaches the axial position sooner than the rest. However, the magnetic attraction must undoubtedly become partially satisfied as soon as the poles *A B* (Fig. 110) approach the magnetic field pole, and this must tend to weaken the rotative impulse. By making the field elliptical the approach would be still more gradual, and the result would be a more equable rotative impulse. The conchoidal field of M. Trouvé may also be recommended. An idea of this form of field will be obtained by supposing the field piece *N* (Fig. 114) to be depressed so that the upper edge of the pole is nearest to the armature and the lower edge most distant from the armature, while the pole *S* is elevated so that its lower edge is nearest and its upper the furthest from the armature.

The field magnet, of which the iron base forms a part, is comparatively massive, and its point of magnetic saturation is not so soon reached as when there is less iron. This is an important quality, especially when the motor is worked to its highest capacity, as well as when the motor is used as a generator of current. When once the point of saturation is reached, then it avails nothing to increase the strength (magnetizing power) of the current, because the iron cores are "full," and will not receive any more magnetism. Any current beyond the amount necessary to produce saturation is wasted. Another argument in favor of a good mass of iron is that the nearer the point of saturation a magnetic metal is, the more current is required to cause a proportional increase in magnetism. When there is plenty of iron, the "margin" between the non-magnetized and the saturation point is wider.

One of the most indefatigable and successful inventors of electric motors has been Mr. Anthony Reckenzaun, C. E., of London. The accompanying illustration (Fig. 115) is a perspective view of his motor made in 1884, and exhibited at the International Electrical Exhibition at Philadelphia that year, by Mr. Fred. Reckenzaun, brother of the inventor. The magnets are, in appearance, somewhat similar

to those employed in the Siemens dynamo, except that, as will be seen from the cut, the cores are in an inclined position, the upper and lower core-ends meeting at a rather acute angle. This arrangement saves space, reduces the weight, and renders the frame rigid. The armature consists of a ring, made up of a series of rings, each of which is again composed of a number of links provided with holes at their ends to receive the bolts which hold the links as well as the rings together. The links, overlap-

shaft inside the armature. These inside collars are in metallic connection with a pair of similar collars at the commutator, where another pair of brushes rests on them, picking up a small current for the internal magnet. This internal circuit forms a shunt to the main circuit. The internal magnet, on being excited, offers two poles, each facing a like-named external field-magnet pole. Hence the passing armature bobbins are exposed to strongly magnetized pole pieces inside as well as outside,

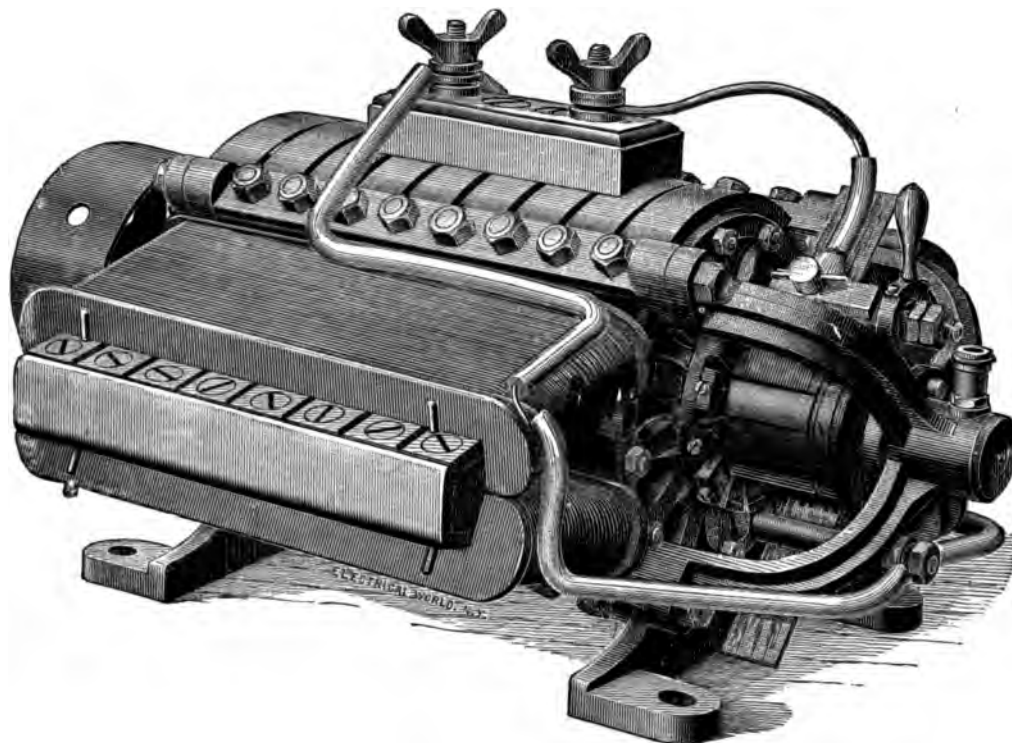


FIG. 115.—RECKENZAUN MOTOR.

ping one another, are insulated from each other in order to avoid Foucault currents. From twelve to thirty-six bobbins surround the ring thus formed and connect with a commutator made up of a corresponding number of sections. A pair of brush-holders carry two brushes, movable within a certain range to adjust the speed of the motor. Inside the armature is a magnet, resting loosely on the shaft by means of rollers. This internal magnet is, in cross-section, H-shaped, having two pole pieces, between which a quantity of fine wire is wound lengthwise, the ends of which are connected to copper brushes which, in running, rub against two brass collars fitted upon the

thereby utilizing also the inner parts of the wire bobbins. The internal magnet is made for larger sized motors, and may be taken out and the motor run without it. On top of the machine are two binding posts mounted on a block of wood, to which the mains are connected. All the iron in this motor is best soft wrought iron, no cast iron being employed. All parts are carefully proportioned for light weight, high efficiency, and strength. In case the armature should require repairing, the bobbins need not be unwound as in some other machines, but any one may be slipped off its section after taking out the nearest bolt, thus saving time, labor, and material.



Fig. 116.—GRAMME MOTOR WITH TAVERDON DRILL.

EALIX

The motor exhibited in Philadelphia was of one and one-half actual horse power. It will strike many of our readers as noteworthy that this motor weighed no more than 106 pounds, which gives a co-efficient of 467, or, in other words, 467 foot-pounds of work per minute to every pound of its own weight. Its bulk was likewise exceedingly small. The motor measured in height nine and one-half inches, width sixteen and one-half inches, and length of shaft twenty and one-half inches—other sizes in proportion. These facts have amply justified its application in England, not only for stationary purposes, but also for various kinds of service where light weight and small bulk, combined with high efficiency, are of great importance, such as in connection with electric launches, telfer lines, mining work, and other purposes.

One of the most important departments of mining operations is drilling and tunnelling, and naturally, as the beds and strata of rocks and minerals near the surface of the earth become exhausted, shafts and galleries are carried deeper and deeper, with a corresponding increase in the number and extent of the difficulties that tend to hinder the successful exploitation of rich deposits. But, thanks to the progress in electric lighting and in the transmission of power, work can be carried on at a greater depth below the surface than ever before, with a decrease of danger and expense. Electricity is now applied to the most varied work in mines, and is found equally available in illuminating the galleries about which float gases of noxious character, in piercing rocks, in hoisting and pumping, and in ventilating; and its use enables the apparatus to be made in small and compact form, the generator of current or prime source of power being at a distance.

The accompanying illustration, Fig. 116, shows the Taverdon drill, with Gramme motor, used in boring subterranean galleries. This invention is a striking example of the transmission of power and the application of electricity to a new and difficult kind of work. Numerous systems of rock drills have been in favor from time to time, the apparatus being run by steam or compressed air, but it is asserted on behalf of this new plan or device that it is far less cumbersome and far more easy to control than any of its predecessors. M. Taver-

don applies electricity to a rotary drill, which is worked by a motor in the manner indicated. In his system, the drills carry at their striking end black diamonds, capable of penetrating the hardest rocks. In order to fix the diamond solidly, so as to keep all its facets properly at work, M. Taverdon employs a hard metallic solder that fills all the cavities. As he could not apply the solder directly to the stone, he first covers the latter by electrolysis with a thin coating of copper. This allows the application of the solder, but does not interfere at all with the parts of the diamond presented to the rock. A special carriage is provided both for the perforator and for the motor. The perforator is fixed upon an upright column adjusted by a spiral spring to the roof and floor of the gallery in such a way as to keep the platform of the car on which it is mounted perfectly steady. It is capable of movement on vertical and horizontal axes, and thus can be set in any desired position. The butt end can be fitted with an ingeniously constructed motor, with a view to the use of steam, compressed air, or hydraulic pressure, indifferently, for driving, but in the electrical arrangement a box replaces the motor and a simple pulley receives and turns with the belt or cable connecting with the electric motor on the rear car. The motor consists of a Gramme octagonal machine, similar to that used in the famous plowing experiments at Sermaize, and its strong cast-iron frame evidently fits it for rough mining work. The pulley at the end of the axis of the motor transmits the power to the box at the end of the drill by the cable, which passes over two other pulleys as shown, one of the latter being adjustable. The generating machine is, of course, outside the gallery at any convenient distance.

On the car carrying the motor is a water tank, from which water is forced to the perforator and is then used to wash away the sand as quickly as it is formed and accumulates. We ought to say here that in another drilling machine of M. Taverdon, the drill or boring tool is fitted direct to the axis of the motor, which is driven in the usual way and is carried on a car. This plan is simpler than the other, and apparently more economical of power, but M. Taverdon speaks highly of the apparatus shown in the illustration and reports that from it he has obtained results equal to those of the best steam drills and better than those with

compressed air. The advantages of the use of electricity for this work are easy to see. The little gallery is not cramped and choked up with steam, air, or water pipes, which, besides occupying valuable space, are liable to leakage and sometimes stop the work while their de-

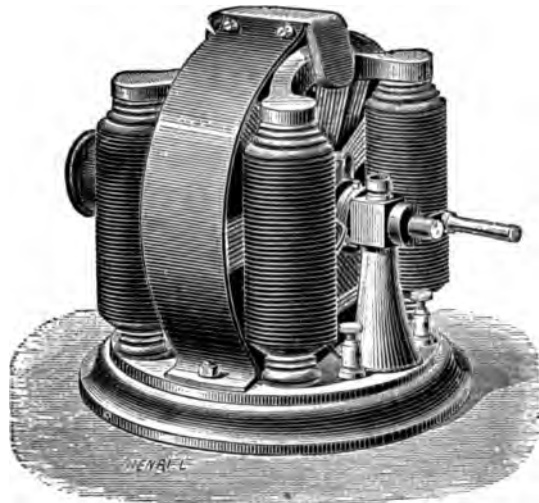


FIG. 117.—LEE-CHASTER MOTOR.

fects are being remedied. A noteworthy feature of the scene is the use of the incandescent lamp; and if necessary the blasting charge in the drill holes can be fired by an electric current.

A fair idea of the extent to which motors of moderate size have already been introduced in France, may be formed from the summary of installations made up to April 1, 1886, by the Compagnie Electrique. This single company had effected forty-two installations, using one hundred and ninety Gramme machines, with a total of 310 horse power. Of these machines, thirty-three are employed for cranes and elevators, forty in driving machinery and tools, fifty-two with ventilators, eleven in pumping, etc., and fifty-four for miscellaneous purposes.

The small motor illustrated in the engraving, Fig. 117, and known in England as the Lee-Chaster, was lately introduced to public notice. It occupies a space of 8 in. by 8 in., and is said to be capable of developing energy equal to nearly three-fourths horse power, and can be started, stopped, or reversed by the simple movement of a switch. It is driven by a battery, which is said to involve the minimum of trouble, which will run for about twenty hours

without recharging, and can then be restarted with fresh solution in a very short time. The cells are charged with Lee's new double bichromate, soluble in its own weight of cold water, and which does not deposit crystals in the pores of the carbons or in the cells. Moulded corrugated carbons are used, and the zincs are so cut as to economize the metal. The cells rest on a tray in a box, and the tray can be raised by means of a treadle until the elements are fully immersed in the solution. Both zincs and carbons are suspended from a board, which forms a lid, so to speak, and the connections are made by means of brass plates, thus avoiding the use of wires. Two wing nuts hold this board to the mechanism of levers, and by removing them, the whole battery of elements can be lifted out, leaving the cells exposed. The zincs and carbons are automatically removed from the solutions when the treadle is released, and the amount of immersion can be regulated to a nicety.

Professors Ayrton and Perry have devoted much attention to the study of electric motors, and as a result they have promulgated the theory,—which we have already drawn attention to in a preceding chapter,—that whereas in the dynamo the field should be of great magnetic strength and the armature a weak one magnetically, the reverse should be observed in the mo-

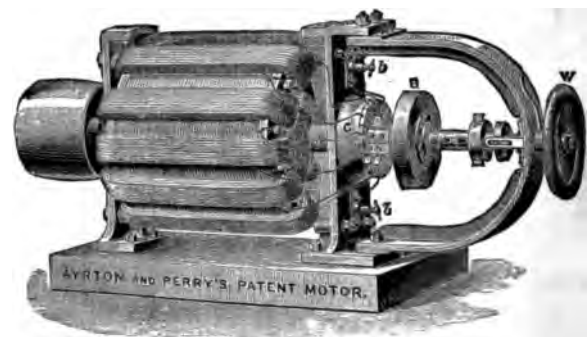


FIG. 118.—AYRTON-PERRY MOTOR.

tor; *i. e.*, the field should be a weak magnet and the armature a powerful magnet. They have embodied their ideas in a form of motor which differs from those of ordinary construction in that the armature is kept stationary while the field magnet revolves within it.

Fig. 118 shows the Ayrton-Perry motor in perspective; Fig. 119 shows the construction of the motor more in detail. The stationary arma-

ture, as will be seen, consists of a laminated cylinder built up of toothed rings of sheet iron, and resembles very much the Pacinotti toothed ring armature. The wires are wound on in sections, joined in series, and at each joint are

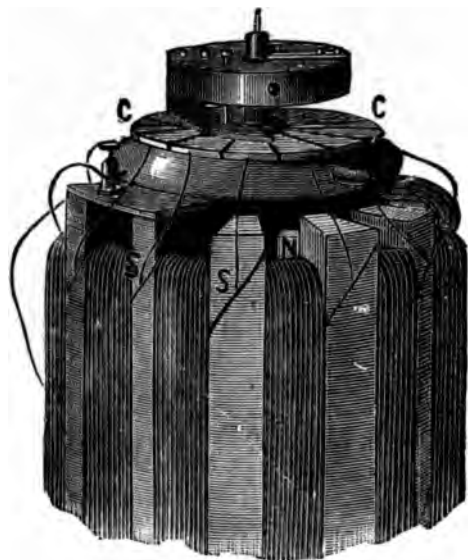


FIG. 119.—DETAILS OF AYRTON-PERRY MOTOR.

connected to a segment of the stationary commutator *C C*. The spindle of the revolving field magnet carries the brushes which revolve with it.

In explanation of the operation of the motor, Professor Ayrton says that wherever the brushes *B* happen to be at any particular moment, there two opposite magnetic poles at *N* and *S* are produced on the armature, as shown in Fig. 119. As the brushes revolve so do these poles, and the brushes, which are carried by the field magnets, are so set that the magnetic poles in the armature are always a little in front of those in the field magnet. The latter, therefore, are, as it were, perpetually running after the former, but never catching them.

Professors Ayrton and Perry have also devoted considerable attention to the regulation or governing of electric motors, and have devised several methods of accomplishing this result. One of their oldest forms, known as their "spasmodic governor," consisted of a trough of mercury, which revolved with the field magnet, and had a wire dipping into the mercury through which the current passed. As the speed increased, the mercury would take the character-

istic parabolic contour of revolving liquids enclosed in vessels, and at a certain speed the wire would be left out of contact with the mercury. The circuit would then be broken, the current cease, and the speed of the motor would fall again. The great objection to this form of governor is that it either supplies full power when the motor is running too slowly, or no power when the motor is running too fast, and hence is incapable of maintaining constant speed.

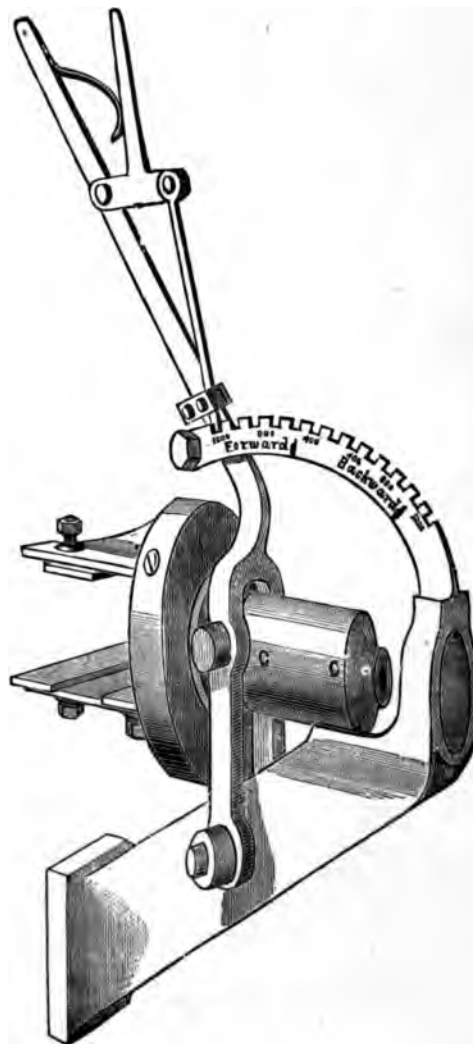


FIG. 120.—REGULATOR OF AYRTON-PERRY MOTOR.

Professors Ayrton and Perry have, however, designed several other forms and experimented with other and more perfect methods of governing electric motors, one among them consisting in winding the motor with two distinct circuits

in such a way that the current passing through one of them magnetizes the iron, causes the machine to act as a motor, and consequently

equivalent to a differential winding and does away with all mechanical governing.

Where it is required to change frequently the speed and direction of rotation of an electric motor, such as upon a tram-car, Professors Ayrton and Perry have applied the method of varying the lead of the brushes. Figs. 120 and 121 illustrate the manner in which this is accomplished. By pushing the handle fully forward the motor revolves rapidly in one direction; when pulled back in the other direction the motor reverses. At intermediate position corresponding lower speeds are obtained. The action of this lead adjuster is as follows:

Attached to the rotating field magnet is the spindle *SS*, which is itself attached to and rotates with the outer collar *CC*. On pushing the handle forward or backward, this collar is moved along the spindle, and the effect of this is to cause a pin to move along the groove *GG* and so cause the inner collar *PP*, which usually rotates along with *CC* and the field magnet, to move a little forward or backward relatively to *CC*. Since the collar *PP* is screwed to the brush-holder, it is possible, even when the motor is running, to shift the brushes relatively to the field magnet together with which they are rotating, and consequently with only *one pair* of brushes to give any desired lead forward or backward. In other cases the lead is altered by means of a wheel and screw which permits of very accurate adjustment.

From the peculiar construction of the Ayrton and Perry motor, it may be operated without any wire at all upon the revolving field magnets. This arises from the fact that the magnetism in the stationary armature induces opposite magnetism in the iron of the field magnets, and, as pointed out before, the brushes are so placed that the magnetic poles in the armature are always just in front of those in the iron, which latter are always running round after those in the former but never catch up with them.

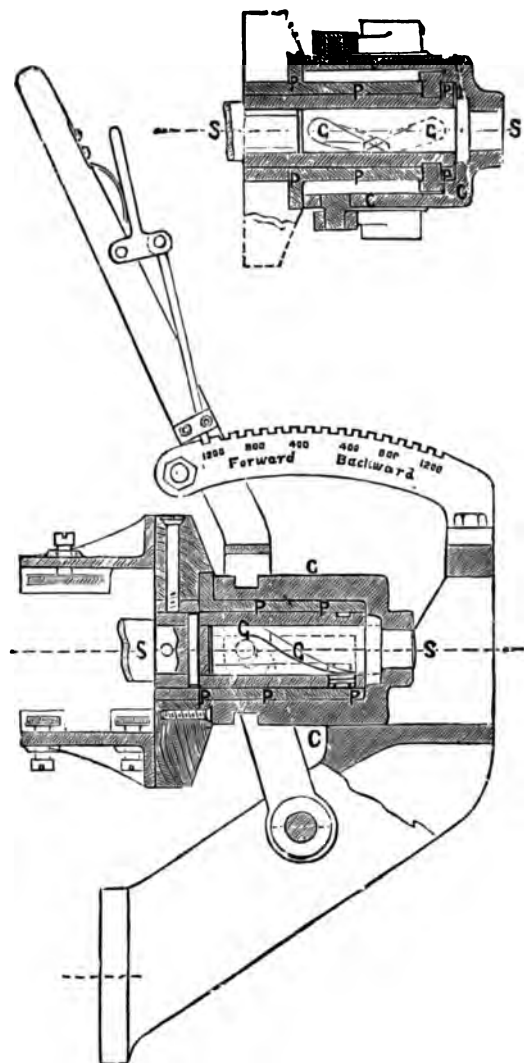


FIG. 121.—REGULATOR OF AYRTON-PERRY MOTOR.

is itself resisted, whereas the current passing through the other circuit tends to demagnetize the iron and stop the motion. This evidently is

CHAPTER IX.

THE INDUSTRIAL APPLICATION OF ELECTRIC MOTORS IN AMERICA.

THERE are, as the previous chapter exemplifies, a thousand and one places to-day where small electric motors are greatly needed and can be used. In large cities, and manufacturing towns of any importance, where hundreds of small steam engines have been in use, each requiring to be fired and attended, the electric motor is of the greatest utility, its chief features of recommendation being that it generates no heat, smoke, or smell, requires scarcely any care the year round, can be entrusted to unskilled hands, makes little noise, is ready to start or stop at a turn of the switch, keeps up a steady motion, is under perfect control, and where a central power or lighting station exists, is cheap to operate. The success that has attended the central power stations already in existence in America attests the appreciation in which such a convenient source of supply is held, and the record is made almost daily of new installations. There can be no doubt that as regards convenience and applicability, electric transmission of power, for the reasons above given, stands without rival. It is often the case, too, that power users crowd into buildings where they pay high rents, solely because in other places they cannot get, or are not allowed to use, steam or gas. The electric motor is highly economic of space, and the wires leading to it can be run out of sight, through the smallest cracks and holes, around corners of the sharpest angle, and to heights or depths at which no one dreams of placing ordinary power-generating machinery.

We have already spoken briefly of the work now being done in Europe, industrially and otherwise, by small motors. The application has not been neglected in America. One of the most successful of recent inventors has been Mr. Griscom, of the Electro-Dynamic Company, of Philadelphia, whose motor during the last four or five years has come into very extensive

application, not only here, but in England as well. Its principal excellence is to be found in the neat and compact design given to it—a feature which recommends it to many uses where other machines would be rejected, especially in domestic work. The motor is of the same type as the Deprez and Trouvé motors, inasmuch as its armature is of the old Siemens form; but the magnetic field in which the armature revolves is entirely different in shape. The motor has received the name of “double induction motor,” from a peculiar phenomenon which was noticed by its inventor while experimenting with it. Ordinarily, the armature is included in the same circuit as the coils on the field magnets. Mr. Griscom once happened to pass a current through the armature circuit alone, the field circuit being disconnected. In this condition the armature, being powerfully magnetized, acted on the iron of the field magnets and tended to move so as to bring its poles in a line with the poles of the field magnet, and there, the magnetism of the armature being reversed, a mutually repulsive effect between this pole and the residual magnetism of the field magnets arose and tended to cause the armature to move away toward the other poles, so that once started the armature would continue to turn somewhat slowly. It was found, however, that if the field circuit, while still detached from the battery circuit, was simply short-circuited upon itself, the motor would begin to revolve very rapidly. Mr. Griscom concluded that by the motion of the armature its lines of force are cut by the field-magnet coils, and thus give rise to a current in the latter which helps to magnetize the field, and he ascribed the phenomenon to the peculiar conformation of the field magnet, which is such as to bring its wire close to the revolving armature. This phenomenon attracted much attention and caused considerable discussion, especially in Europe.

One sufficient theory, as opposed to the above, is that the closed circuit simply prevents the induced magnetism from diminishing on account of the "Lenz effects" which arise in the closed circuit, and that as the magnetism is slightly increased at each turn by the induction of the armature, the magnetic intensity of the field soon reaches a maximum. Whatever induction is produced by the lines of force of the armature must necessarily be of a nature to oppose the motion instead of helping it. This inference is indeed a valid consequence of Lenz's law. When the field magnet is in the same circuit as the armature, and fed from a battery current, the phenomenon does not oc-

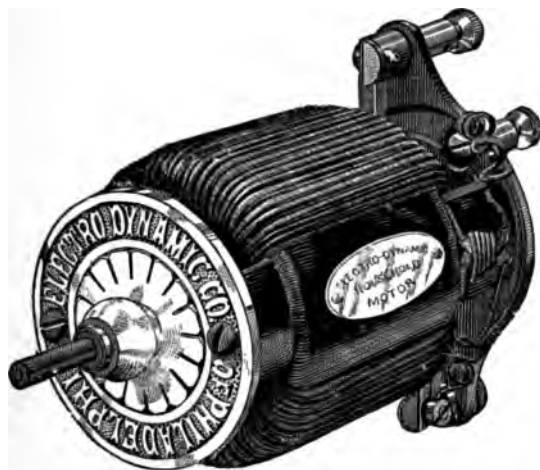


FIG. 122.—THE GRISCOM MOTOR.

cur after the magnets have reached saturation, which takes place almost instantly; so that the term "double induction" is a misnomer. However, the motor can sustain its reputation quite well, even without the supposition of double induction, for it certainly attains a remarkable efficiency. It is said that it can lift 2,000 times its weight (forty ounces) in one minute, when working with the full battery power. This gives it a capacity of nearly one-sixth of a horse-power.

The motor is remarkable for the small space it occupies, due to its neat and compact design, shown in Fig. 122, which is nearly full size. The armature is entirely encased by the cylindrical electro-magnet within which it revolves, and by the metallic caps or discs fitted to this cylinder at each end. The cylindrical field magnet is composed of a cylinder of soft iron wired in two large coils, each of which covers nearly one-half of the cylinder, the space left

between the two coils at opposite sides of the cylinder constituting the magnetic poles of this cylindrical electro-magnet. The current which passes through the wire on this magnet circulates in opposite directions in each coil or section, so that both coils combine to produce a north pole in one of the open spaces and a south pole at the other. The result is practically the same as if two U electro-magnets were brought together with like poles in opposition, these forming a circular magnet with two consequent or combined poles, one at each junction. The iron of the cylindrical magnet projects laterally at each pole, and to these projections an ornamental brass disc is screwed firmly at one end, as shown in the figure. This disc forms one of the bearings of the armature shaft, which passes through it, and at the same time serves to protect the armature from injury. At the other end of the motor another brass plate is similarly fastened to the lateral projections of the poles of the cylindrical magnet. The shaft of the armature has a bearing in this plate also. The binding posts which receive the current from the battery pass through this plate. In the figure one is shown at the top and the other a little to the side of it. The binding post shown at the top is prolonged on the other side of the metallic cap, and carries one of the brass springs or brushes which serve to convey the current to the armature by pressing on the commutator. The other brush, touching on the opposite side of the commutator, is held in place by a special screw device attached to the metallic cap. The armature and the field magnet are connected in series, as may be readily seen from the figure. The current, entering the armature by the upper commutator spring, leaves it by the lower, from which it passes to the field magnet, whence it goes to the second binding post.

The Griscom motor weighs only forty ounces, and, as said above, can develop a power of 5,000 foot-pounds per minute (that is, nearly one-sixth of a horse power) without difficulty. It has been in great demand for working sewing machines, and is also being used very extensively for many other industrial purposes. It has proved of great utility and convenience to surgeons, and especially to dentists, in driving various surgical instruments. The well known dental engines used for rotating the excavating drills used to remove the decayed portions of

teeth are all operated by a treadle, which not only obliges the operator to remain in fatiguing positions for several hours, but requires him to keep up a monotonous and tiresome movement. By a clever adaptation of the electro-dynamic motor to the flexible shaft of a dental engine, these disadvantages are obviated. The apparatus is suspended either by balanced cords from the ceiling, or from an adjustable arm, which allows it to remain balanced at any height or desired angle, thus relieving the operator of the weight of the apparatus and permitting him to manipulate the drills as delicately as a pen.

nets are divided so that there are two or more circuits around the core. By suitable devices these are so related that they can be thrown into series or into multiple arc, or into other combinations when there are more than two circuits, for the purpose of changing the strength of the magnetic field, to suit the electromotive force and strength of current supplied to the motors.

The armatures are modelled in principle after the Gramme, but their construction is much improved, especially in respect to the manner of mounting them on their shafts. Instead of

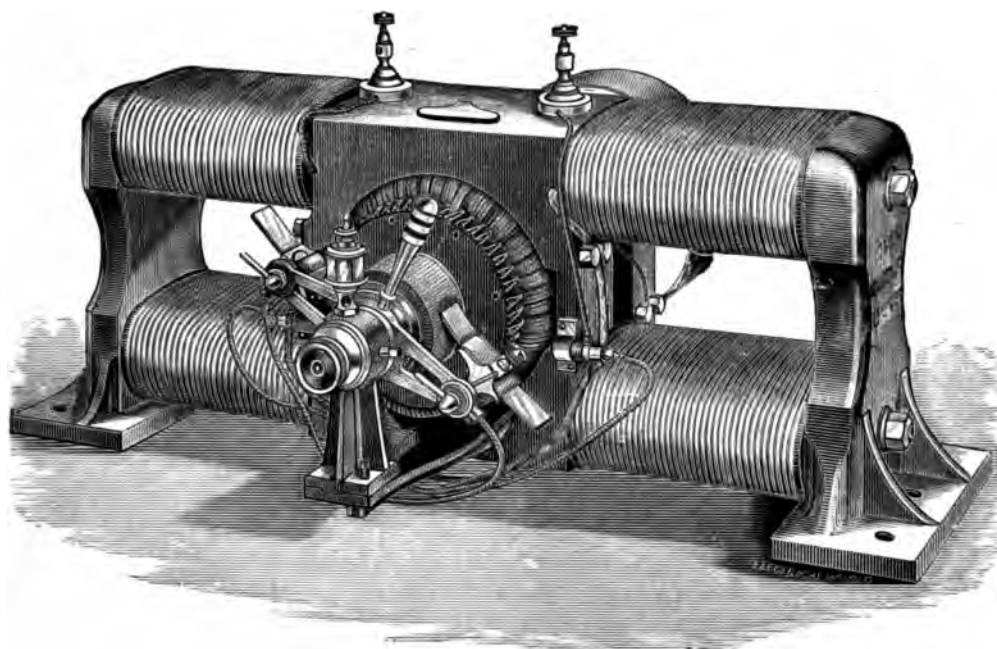


FIG. 123.—DAFT GENERATOR OF 1884.

New forms of the Griscom motor are, we understand, now being designed and constructed for more general use.

To this department of electricity, as well as to the use of motors on railways and street-car lines, Mr. Leo Daft has paid considerable attention. We illustrate here some of the machines made by him in 1884,—it being unnecessary to go further back. Fig. 123 shows a typical Daft generator, already referred to in the preceding chapter on American electric railways, and Fig. 125 a motor. The field magnets are made after what is called the Siemens plan. That is, they lie horizontally, have consequent poles, one above and the other below the armature. They are series wound, but the coils of the field mag-

wood, suitably insulated metallic spiders and connections are used for the purpose. Thus there is left a space within, around the shaft, through which air can circulate for ventilating and cooling purposes.

As high speed is favorable to the efficiency of electric motors, they are provided with gearing so that the armatures may be run at high speed, but communicate to the driving pulley only a moderate rapidity of rotation. With that end in view, the armature shaft is lengthened on the end opposite the collector; two bearings are there provided, and between them there is a steel worm gearing with a phosphor-bronze wheel on the shaft carrying the driving pulley. This makes a good wearing combina-

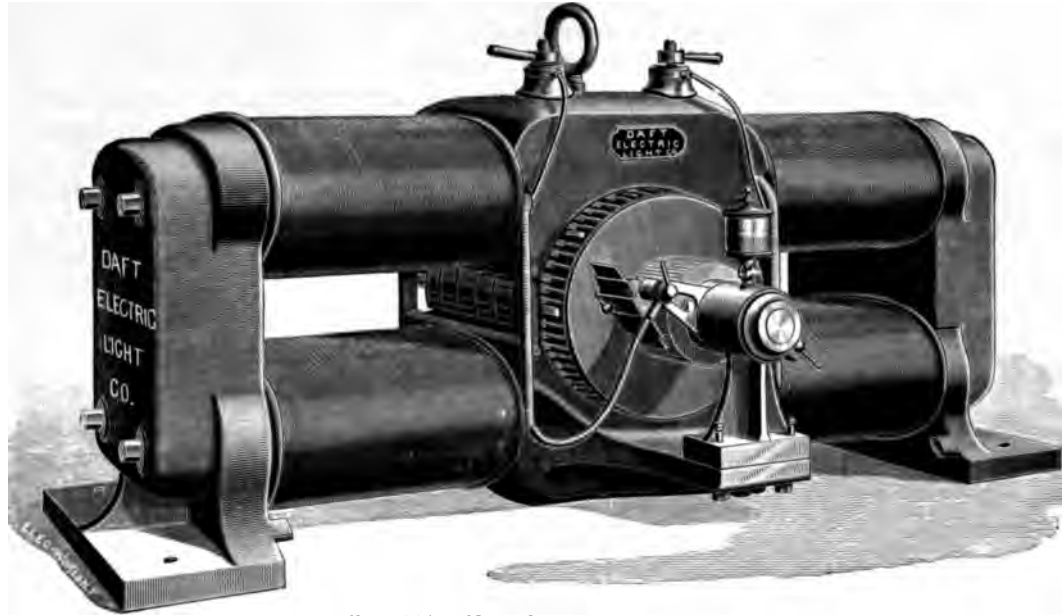


FIG. 121.—NEW DAFT GENERATOR.

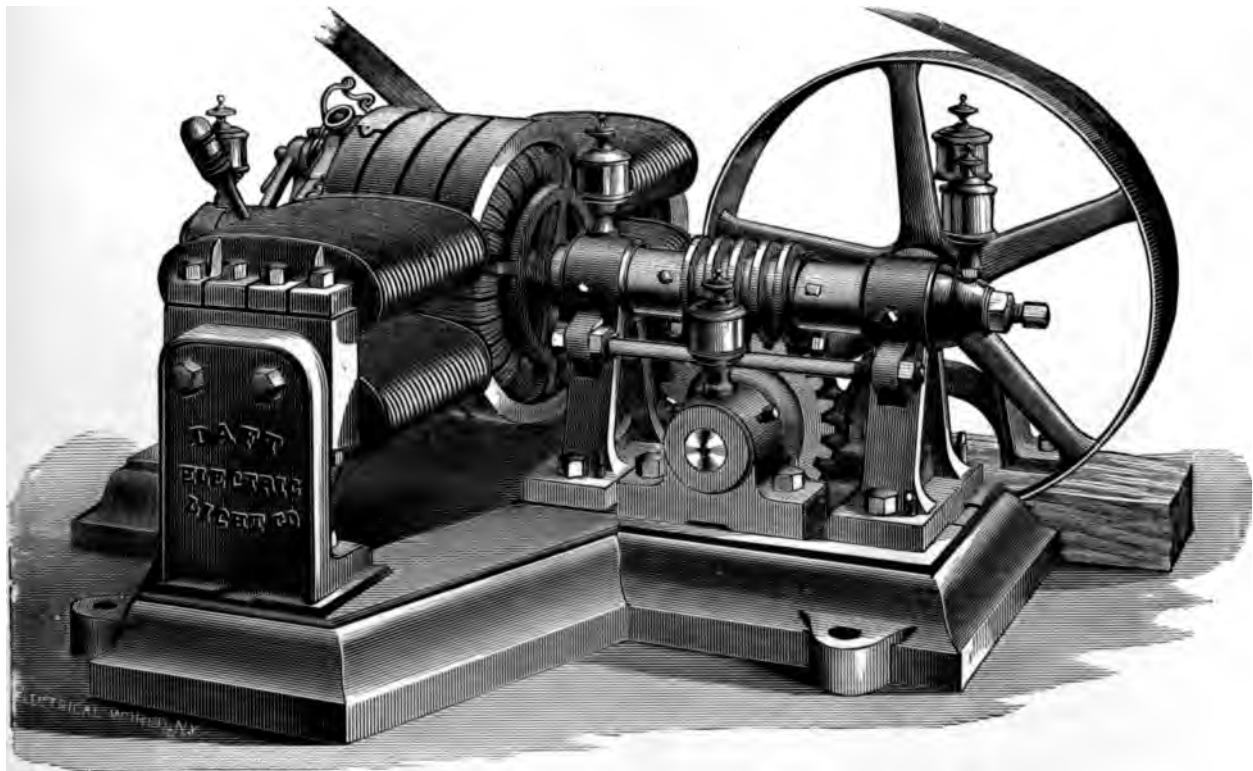


FIG. 125.—DAFT MOTOR WITH GEARING.

tion. The bearings of the armature shaft are of phosphor-bronze, and an end plate and adjusting screw are provided to receive the thrust of the shaft due to the gearing. The whole makes a very practicable combination, taken in connection with the means of varying the field strength of the magnets of both generator and motor.

Two of the motors have been in use in Spruce street, New York city, one since January, 1884, and the other since April, 1884, giving great satisfaction in the operation of freight elevators which have a capacity of 2,000 pounds with a speed of from thirty to thirty-five feet a minute. One of them was also put to work as long ago as 1883, in the steam mills, Newburgh, N. Y., to operate an elevator raising a load of 1,800 pounds. The New York elevator motors run continually during working hours. When not engaged in raising the elevators they run faster than when doing work. Consequently their counter-electromotive force cuts down the current supplied to them to the point of supplying the energy necessary to overcome the friction of the motors and their gearing. The average speed when at work is 1,200 revolutions per minute. The difference of potential at the binding posts is about ninety volts. The current varies with the load, but averages about twenty-five ampères to each machine. The actual power recovered is said to be sixty-six per centum.

The armature of the generator has a resistance of 0.23 ohm. Its speed is 1,100 turns per minute. Its electromotive force is ninety volts, and its extreme practical current capacity seventy ampères. Hence it can deliver 6,300 voltampères of electrical energy, or $\frac{6,300}{746} = 8.44$ horse power. Fig. 124 shows the latest type of Daft generator.

With a Daft motor of this type, and of one and one-half horse power, *The Electrical World* gave an interesting exhibition of printing by electricity at the International Electrical Exhi-

bition in Philadelphia, September and October, 1884. For six weeks, the regular and special editions of the paper were printed from electrotypes on a 31x46 Cottrell press made specially by Messrs. C. B. Cottrell & Sons for the occasion. Although this was not the first time printing by electricity had been accomplished, the idea was quite new to a great many visitors to the exhibition and attracted unusual notice. The motor and press worked without the least

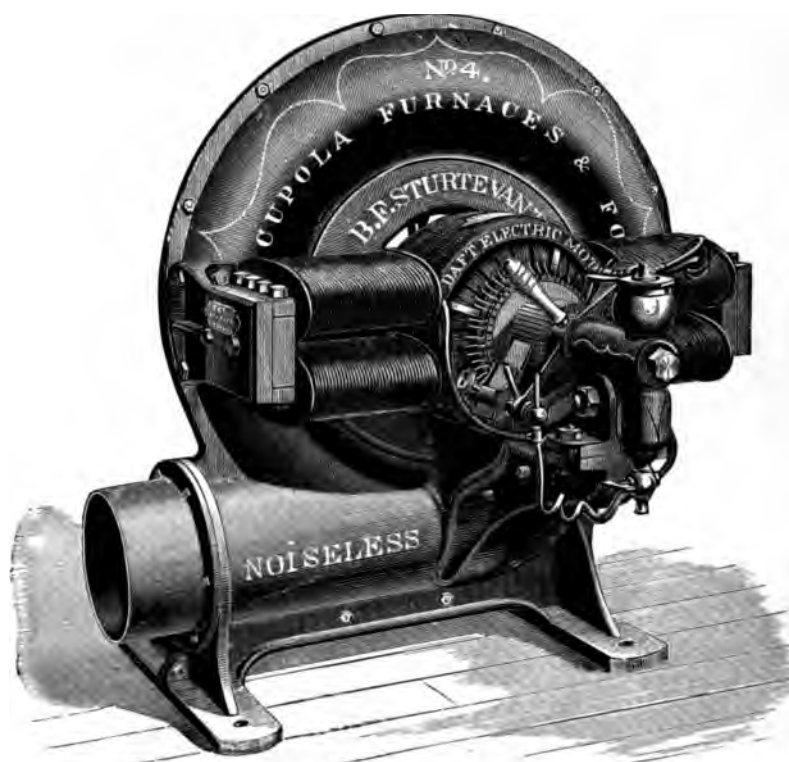


FIG. 126.—DAFT MOTOR WITH BLOWER.

trouble, under the supervision of Mr. Clarence E. Stump, the business manager of the paper, who had charge of the exhibit and who found the printing to compare very favorably with that done on a press directly actuated by steam. It may be mentioned here, as of interest, that the Ilion (N. Y.) *Citizen* was printed by a Parker motor, March 14, 1884, through a break-down of its steam engine; and that the Lawrence (Mass.) *American* has been printed daily since July 6, 1884, by an electric motor. In a letter written to one of the present authors, in October, 1884, Mr. George S. Merrill, proprietor of the *American*, said: "We formerly used a ten horse-power engine, necessitating the employ-

ment of an engineer, but the employment of the Edison Company's power gives a saving in expense of more than thirty-three and one-third per cent. The speed is uniform and the power satisfactory in every respect." The motor is used to run several cylinder and job presses.

Fig. 126 shows a Daft motor attached to a No. 4 Sturtevant blower, the two together forming practically one machine. In the blower illustrated, which requires two horse power, three speeds are obtained, of 800, 2,000, and 2,700 revolutions per minute, by changing the resistance of the field, thus doing away with outside resistances and entailing no loss of work due to their employment.

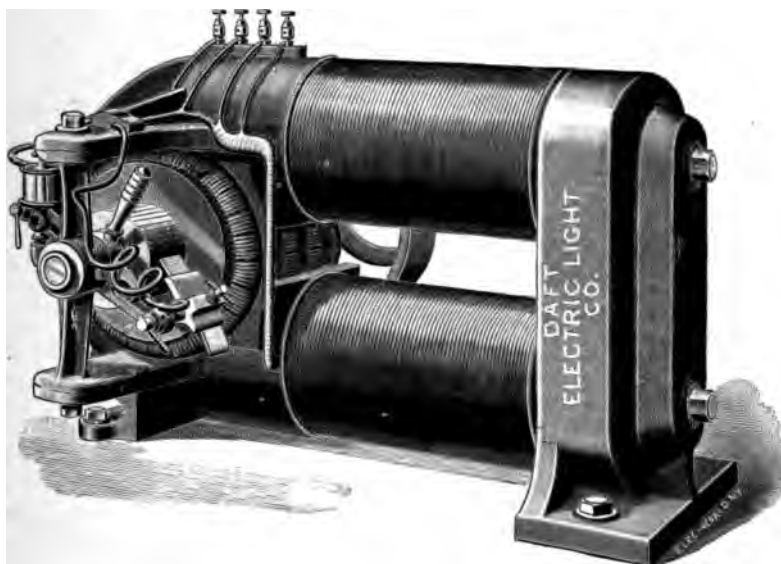


FIG. 127.—NEW DAFT MOTOR.

For some time past, Mr. Daft has devoted his energies to meeting the requirements of the various central power stations established to operate under his system. The success experienced by these power stations, especially in Boston and Worcester, Mass., has induced him to enter upon the manufacture of a more extended series of sizes and to remodel his machines to meet the requirements of more varied work.

The form which he now employs is shown in our engraving, Fig. 127. It will be seen that the field magnets are of the simple horseshoe form, and that the armature is of the Gramme type, as in Mr. Daft's previous models. The machine is designed to deliver normally six horse power, but upon test it has been driven

to as high as eleven horse power without injurious effect.

Constant speed at all loads is naturally the first requisite in an electric motor designed for stationary power plants, and hence accurate regulation must be provided for. The present machine, according to Mr. Daft, maintains its speed within two per cent., between maximum load and no load. To obtain this result, the machine has its field wound compound with three different windings. Of these one is a "series" and the other two are shunts.

The coils are wound on spools which are slipped over the wrought-iron cores, and can readily be removed for examination when necessary. The principal data regarding the machine are as follows:

Electromotive force designed for	100 volts.
Resistance of armature,	0.15 ohm.
" " series coil in field,024 "
Resistance of first shunt in field,	32.73 ohms.
Resistance of second shunt in field,	7.30 ohms.
Power,	6 h. p. nom.
Number of revolutions per minute,	1,300.
Weight,	875 lbs.

It is evident that in a system of electric distribution where power is furnished and sold to various consumers, it is necessary to provide some means of controlling the maximum amount of power

each customer may use, as well as to prevent injury to the machine by unskilled persons starting it with the full force of the current before the inertia of the armature is overcome and it has attained speed enough to develop a suitable working resistance or counter-electromotive force.

Mr. Daft has provided for these necessities, and places upon the premises of each power consumer an apparatus designed for this purpose. It is shown in Fig. 128. Figs. 129 and 130 are details which are shown in outline in Fig. 128.

It will be seen that mounted on a shaft supported in journals is a gradually increasing cam *A* of insulating material, and this cam is ro-

tated by a toothed wheel *B* on the same shaft, and a worm *C* meshing with the wheel and operated by a crank from the outside. Upon the periphery of the cam are arranged strips or sections *D D* of copper, and supported in standards and insulated from each other are two contact pieces *E E*, which bear upon the strips on the cam. At the highest part of the cam is

so that the operator may properly manipulate the switch and know the position of the parts inside by the location of the indicator with reference to the words "off" and "on."

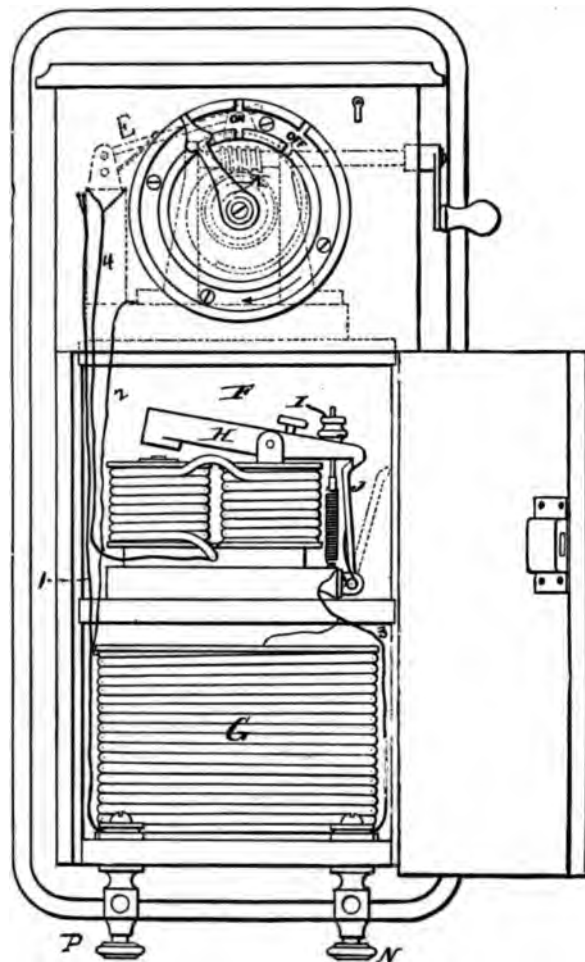


FIG. 128.—DAFT MOTOR—LIMIT SWITCH.

placed a transverse conducting strip *M* insulated from the other strips and adapted to complete the circuit direct between the spring contacts. In the bottom of the box is a resistance coil *G* and a cut-out switch *F*, the armature *H* of which is adjusted by a regulating screw *I* to withstand the desired degree of attraction before moving and to retain the snap switch *J* in position.

An indicator *K* is attached to the cam-shaft, which shows the relative position of the cam,

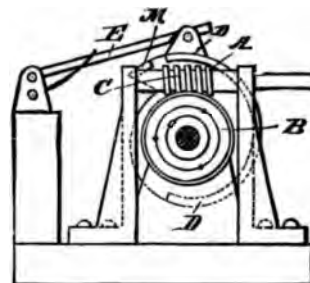


FIG. 129.—DETAILS OF LIMIT SWITCH.

The circuits are traced as follows: Entering at the post *P* the current passes, by wire 1, to one of the spring contact pieces *E*, which, in its normal or "off" condition, rests upon the insulating material of the cam, and no current can pass. As the cam is slowly rotated the contact brushes bear upon the conducting-strips, one of which is electrically connected to the frame, and thus by the wire 2 through the resistance coil to wire 3 and out by post *N*. When both contact pieces bear upon the cross-strip *M*, the current passes through the same and the contact piece, by wire 4, through the cut-out and to post *N*, short-circuiting the resistance.

The operation of the apparatus will now be readily understood. Supposing the indicator to point to the word "off," the spring contacts

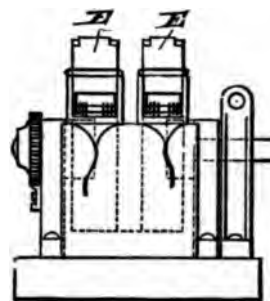


FIG. 130.—DETAILS OF LIMIT SWITCH.

will rest upon the smallest part of the cam, and as the strips on the periphery do not extend to this part, the contacts will rest upon the insulating material of the same and no current will pass. If, now, the handle is turned, the cam will be slowly rotated, bringing the conducting strips under the spring contacts, and as these

strips are connected to the resistance coil, the current will first flow through the coil, and the armature of the motor will not be endangered; and as it requires a number of turns of the worm to complete the rotation of the varying-cam, some little time will elapse after the first

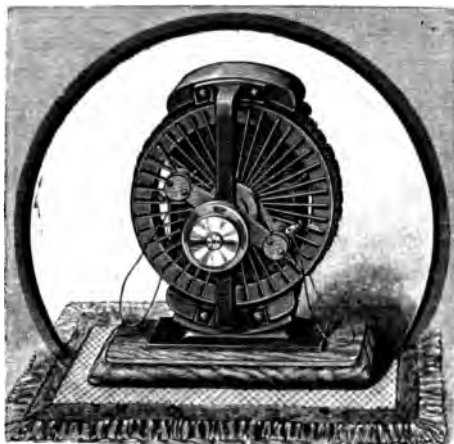


FIG. 131.—SMALL VAN DEPOELE MOTOR.

contact of the strips with the spring contacts before they will reach the transverse conducting-strip, when the resistance will be cut out and the direct circuit be completed through the strip and spring contacts, permitting the motor to have the full force of the current, and the indicator will point at "on." It will be seen that, during this operation, the armature of the motor will have attained considerable velocity, thus developing a suitable working-resistance to prevent injury to the brushes or other parts.

As stated before, there is a cut-out added, which prevents the use of more power than is contracted for. The coil of the cut-out is placed in the main circuit, and the armature may be adjusted so as to allow a current of a certain specified strength to pass without operating it; but any abnormal increase due to overloading the motor or otherwise would cause it to be attracted toward the magnet core, thereby releasing the snap-switch and breaking the circuit. The adjusting screws permit of regulation for a wide range of current, and can be adjusted for any desired consumption of power. The cut-out box is kept locked and under the control of the parties at the central station, and the consumer is limited, therefore, to the use of the amount of power contracted for. In the

event of an attempt to take more power than contracted for, the speed of the armature is reduced, the internal resistance of the machine being thereby decreased, the flow of the current will quickly reach the point at which the adjustable cut-out has been set, when the circuit is severed and the consumer is obliged to notify the company before the machinery can be placed in working order again. The use of the gradually increasing cam is also valuable in preventing the operation of the cut-out when the machine is started, as otherwise an abnormal flow of current is likely to occur which would operate the cut-out. It also furnishes a safe and effective stop-switch, for as soon as the increasing cam in its rotation causes its highest part to pass the spring contacts, they will instantly fall upon the smallest insulated part of the cam, thus severing the circuit without the possibility of forming an arc for any appreciable time. If at any time there should be a sudden abnormal increase in the current in the line from any cause, the cut-out operates to prevent injury to the machine.

We illustrate next two industrial types that have been made by the Van Depoele Company.

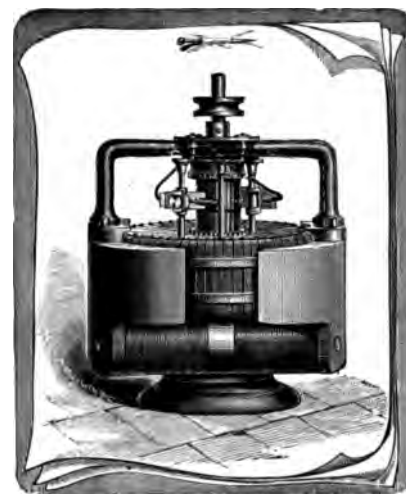


FIG. 132.—SMALL VAN DEPOELE MOTOR.

Fig. 131 shows the small motor for light work. The principle of construction will be easily seen from the cut. The ring armature has numerous sections, insuring steady motion, and the pole pieces are of special form. The design of the whole is simple and symmetric; there are no parts to get out of order, and with a few

drops of oil occasionally, these motors will run for years without the slightest irregularity, and without perceptible wear. The battery furnished with them is a bichromate, of improved pattern, which can, of course, be connected with or disconnected from the motor at will by means of a switch, and can be put away in any convenient place in a box.

Fig. 132 is a motor for running large horizontal fans, which can be coupled directly with the vertical shaft. When it is necessary to run several fans at once, instead of using several

The base carries the upper core and pole of the field magnet attached permanently to it. The under core and pole is hinged at the rear of the motor just above the binding post there shown. It is so hinged for the purpose of changing the speed of the motor to suit requirements by moving the under pole to or from the armature by means of a connecting rod and treadle not shown.

When the pole is moved away from the armature its attractive influence is not so strong, and therefore the power and speed are decreased.

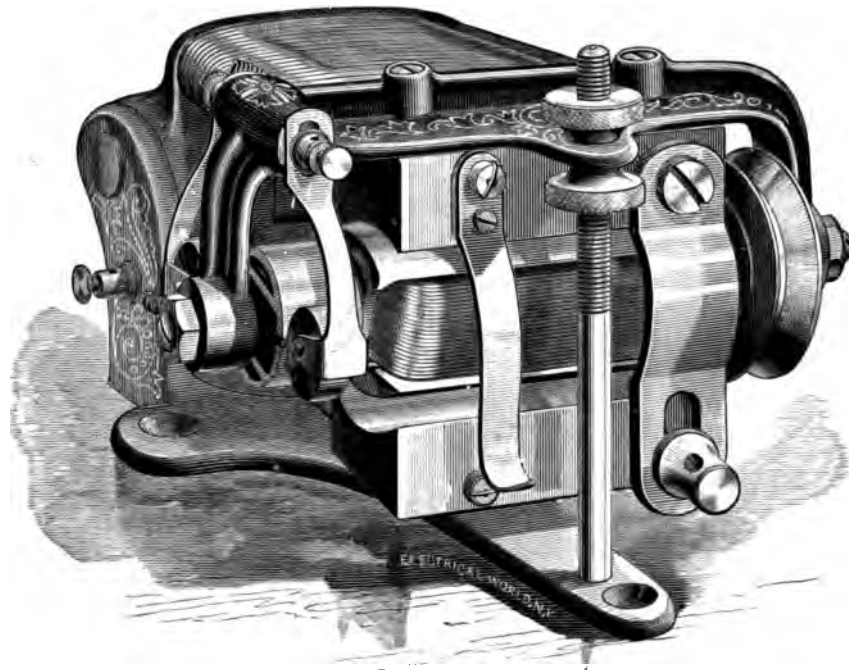


FIG. 133.—DIEHL MOTOR.

motors, one motor of sufficient power for the lot can be used, with the intervention of belting in the ordinary way.

At the Singer Manufacturing Company's exhibit in the International Electrical Exhibition at Philadelphia in 1884 were seen several sewing machines run by various electric motors invented by Mr. Philip Diehl, the inventor engaged by the sewing machine company, and one whose other work in the practical application of electricity has been marked by great originality.

One form of motor is made part of the fly-wheel of the sewing machine, and the one we illustrate by Fig. 133 shows the motor at about two-thirds size.

If the pole be swung downward until its lowest limit is reached, the electric circuit is broken entirely at the point where the button on the under pole and the spring projecting from the upper pole meet. The post with the two jam nuts on it is for the purpose of fixing the position of the upper pole.

The armature core axis and pulley are cast as one piece of iron, and the armature is of the Siemens H type. One pole of the armature core is extended and bent so that the axis at the commutator end is in its proper place, and there is a space between this extension and the other pole. At the other end of the other pole a like extension for the pulley axis is provided. Thus there are longitudinal and transverse spaces

lengthwise around the core to receive the coil; and yet the poles are not connected by iron except within the coil.

The commutator is of the kind usually attached to bipolar armatures—that is to say, it has two sections.



FIG. 134.—DIEHL MOTOR.

One of the most novel and ingenious of recent motors is that shown in Fig. 134. This motor is also the invention of Mr. Diehl. The present motor, though built on the same principle as the one exhibited by the inventor at Philadelphia, 1884, and illustrated above, differs con-

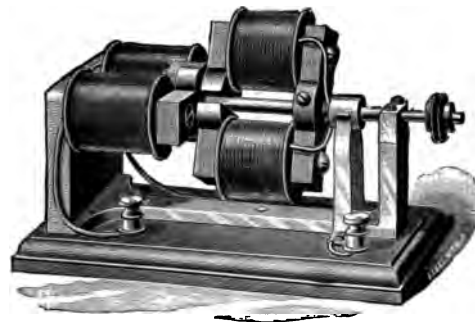


FIG. 135.—KEEGAN MOTOR.

siderably from it in construction and general appearance.

By referring to the engraving, it will be seen that the field magnets are placed vertically and hinged at the top, being supported by two side rods, cast solid with the base. The lower ends of the field magnets encircle the armature,

which is also carried by journal bearings in the side rods.

The method of regulation of the motor consists in separating the pole pieces from the armature. This is accomplished by means of two connecting rods fixed to the lower ends of the magnets and joined together by a pin which lides in a slot on the upright. A rod connected to the pin serves to raise and lower the upper ends of the two connecting rods, and in doing so the field magnets are separated or brought together, as the case may be.



FIG. 136.—PENDLETON MOTOR.

When used in connection with a sewing machine, the motor is secured to the under side of the table in an inverted position, and the regulating lever connected to the treadle. In this position the field magnets fall apart of their own weight and the machine does not work. It is only when the treadle is pressed and the magnets are brought together that motion is obtained. It is evident that by varying the distance between the armature and the magnets any desired speed can be obtained for fast or slow work. The motor is finished in a very ornamental style, and runs very smoothly. The armature shaft is provided with a pulley, and

its end is bored so that the power can be transmitted by belt or applied directly, as when driving a fan.



FIG. 137.—ARMATURE OF PENDLETON MOTOR.

Another good motor recently devised for small work is that of Dr. V. E. Keegan, of Boston. The main objects sought have been those

five volts for the standard size, according to the power required. The motor, which is made by Mr. Wm. J. Keenan, of Boston, is neatly built. The commutator is platinized to prevent corrosion.

At a meeting of the electrical section of the American Institute, held in New York, in July of the present year, Mr. John M. Pendleton exhibited to the society a small electric motor of his own design which embodies several novel features. Mr. Pendleton remarked that the general introduction of electricity had drawn considerable attention to electric motors, from the recognized fact that power is not only more

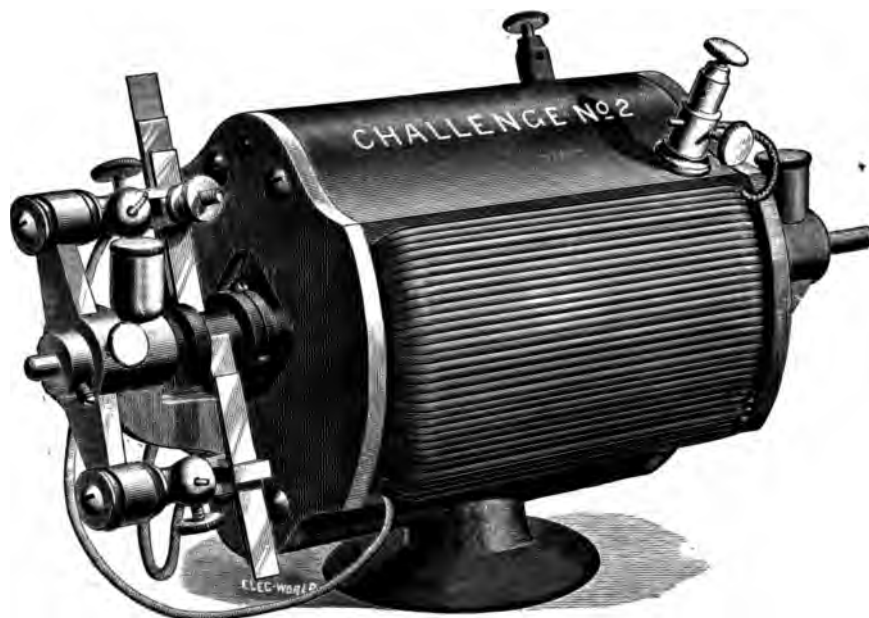


FIG. 138.—PENDLETON MOTOR.

of simplicity of apparatus and economy in running. As the illustration shows—Fig. 135—the motor consists of two horseshoe electro-magnets, the one acting as field, the other as the armature. The pole pieces are extended inwards until they come within a quarter of an inch of each other, and at this point, where the magnetism is the strongest, each takes the form of a semicircle; thus, instead of an alternate action of attraction and repulsion, the two forces are always acting together, and hence the effect of the induction current, according to the inventor, is largely neutralized. In order to make the motor economical of battery material, it is wound for high resistance, requiring a current of only two amperes at from ten to twenty-

readily transmitted by electricity, but also on account of the facility with which it may be subdivided and distributed without loss—a point in which neither steam nor gas engines can compete with it.

The motor, which is shown in perspective in Fig. 136, weighs forty ounces, and is capable of developing power sufficient to run a sewing machine or other light running apparatus, such as a dental drill, mallet, or a fan.

The armature of the motor, which is shown detached in Fig. 137, is of the three-pole type, and each of the three segments of the commutator is consecutively cut out in such a manner as to reverse the polarity of the pole of the armature so that for one-half the distance of the

pole-piece attraction takes place, and during the other half repulsion.

This construction obviates any dead point, and the motor starts instantly at any position of the commutator. This is evidently an indispensable quality in a motor designed to operate intermittently, stopping and starting at frequent intervals. Such work also frequently requires a change in speed, so as to run fast or slow, and this has also been provided for, by making the brush-holder adjustable. The latter is controlled by a spring which normally maintains it at the position of maximum speed. By ro-

tating the brush-holder, however, the position of contact, and hence the speed, can be varied at will from the maximum down. This shifting of the brushes does not require any manipulation by hand, but is accomplished by a cord attached to a treadle, thus leaving the operator's hands free to guide the work.

The engraving, Fig. 138, shows a larger size of the same type. The latter weighs twenty pounds, and is said to be able to develop as high as one-quarter horse power.

(The latest American motors of the industrial class will be found in Chapter XII.)

CHAPTER X.

ELECTRIC MOTORS IN MARINE AND AERIAL NAVIGATION.

THE use of electric motors in marine and aerial navigation has been chiefly studied with a view to obtaining the necessary current from storage batteries. It is true that bichromate of potash has been employed, but storage is regarded by almost all who have investigated the subject, as the ultimate means to be adopted in any practical work on a large scale.

The experiments on the Neva, fifty years ago, have already been noticed. There is nothing to record in the present chapter from the efforts of Jacobi until we come to those of the ingenious and versatile Trouvé of Paris, who put a small electric boat on the lake at the exhibition in 1881. This boat, which had previously been shown in operation on the Seine, was equipped with a double motor, or, in other words, with two bobbins put close together fixed on the rudder-head. The current was furnished by a bichromate of potash battery placed in the middle of the boat. Motion was communicated by means of an endless chain to a small screw fitted in the rudder itself. A speed of about three and one-half miles was obtainable, with a load of four or five passengers, and the battery was only active when wanted.

The launch "Electricity," operated on the Thames in 1882, is said to have been the third boat propelled by an electric motor. It was twenty-five feet in length and about five feet in the beam, drawing one foot nine inches forward and two feet six inches aft, and was fitted with a twenty-two inch propeller screw. On the trial trip on the Thames there were stowed under the flooring and seats forty-five electric accumulators of the Sellon-Volckmar type, which had been charged by wires leading from dynamos, and were calculated to supply power for six hours at the rate of four horse power. These storage cells were placed in electrical connection with two Siemens dynamos, furnished with special reversing gear and regulators, to serve as motors to drive the screw-

propeller, the arrangement being such that either or both of the motors could be switched into circuit at will. The party on board consisted of four persons, Mr. Volckmar being one of the number. The launch would carry twelve passengers. The ability of the boat to go forward, slacken, or go astern, at the pleasure of the commander, was satisfactorily tested, and a speed of eight knots an hour was made against the tide. The return trip from London Bridge to Millwall, coming down with the ebb, was made in twenty-four minutes, the mean speed of the vessel being nine miles per hour. The actual expenditure of electric energy was calculated to be at the rate of three and one-eleventh horse power.

During 1883, a launch built by Messrs. Yarrow, of England, and shown at the Vienna Electrical Exhibition, attracted considerable attention. The boat was forty-six feet in length, and was capable of accommodating some forty-nine or fifty passengers—an extraordinary number, in comparison with the carrying powers of any steam launch of corresponding dimensions. The whole of the boat, with the trivial exception of a small space at the stern—hardly more than is sufficient for the "man at the wheel"—was available for use instead of having, as is the case of the best constructed steam launches, a large portion of the centre of it occupied by the machinery. Comfortable seats extended through the entire length of the launch on each side, and there was nothing to interrupt a promenade from end to end of it.

The motive power lay *perdu* in seventy boxes, each of one horse power, stowed away under the floor of the launch, and at the end there was a Siemens D 2 type of motor, the spindle of which was continued so as to form the shaft of the screw. There was no gearing whatever between the dynamo and the screw, to which 600 to 800 revolutions per minute could be imparted without the slightest noise, and a speed

of from eight to nine miles an hour kept up with far less than the usual amount of wash. There was no noise nor heat, nor smell of machinery, nor smoke, and, as we have said, the whole of the boat was practically available for use, without any obstruction of boilers and engines. The advantage of such a motive power is thus in many ways quite obvious, and the cost of the launch complete in every respect was, it is said, only about \$3,000.

Since 1883 various other trials have been made, and experiments tried. One of the most successful workers along this line has been Mr. Reckenzaun, who at the present time has a launch running successfully on the Thames fitted with his motor and secondary batteries.

In June, 1885, Mr. Reckenzaun took the Duke of Bedford for a cruise in the electric launch "Australia," on the Thames. The Duke was so pleased with the performance of the "Australia" that he decided to order a boat of similar design, but of more elegant appearance, and the Electrical Power Storage Company was intrusted with the construction of the propelling apparatus of this new vessel, which is some three feet longer than the "Australia"; the internal arrangements, however, are very similar. Twenty-nine E. P. S. accumulators are placed in a box in the centre of the boat, this box serving as a seat for passengers; the cells actuate a Reckenzaun motor, and the speed obtained is of the average rate of six knots per hour for four and a half hours. The accumulators of this boat serve also for lighting the yacht when the electric launch is suspended from the davits, and the cells are charged from the dynamo which usually lights the "Northumbria." The official trial took place at Westminster, in the presence of numerous spectators. Mr. Reckenzaun has had several designs of electric boats in progress, for some time past, embodying further substantial improvements. One of these is being executed to the order of the Italian government, and a second for an Indian prince; the former is for war purposes and the latter for pleasure. The prince's launch is to be fitted most luxuriously, and electrically lighted, even the fans being actuated by electricity.

During September of the present year, the launch "Volta," fitted with two Reckenzaun motors and a set of accumulators, made the trip from Dover to Calais and back, with ease and

safety, the batteries being charged but once for the whole journey. The "Volta" is 37 feet long, has 7 feet of beam and is 3½ feet deep. She is built of galvanized steel plates. Her propelling power consists of sixty-one accumulators, each eight inches square, placed as ballast under the floor with the motors. The accumulators were charged over night from a dynamo worked by a small steam engine in a carpenter's shop facing Dover harbor, the connection to the boat being by short sections of a cable. Seven passengers were carried and a speed of over six miles an hour was maintained, while over twelve miles was reached.

As in marine navigation, so with aerial—the use of electric motors has been of an experimental character, and yet its results are most significant and encouraging. Up to 1881, one of the greatest desideratums in ballooning was a light motor that would not require fire and would not be subject to loss of weight in operating. Clearly, the electric motor was the thing wanted, and M. Gaston Tissandier applied himself to the problem of adapting the means to the end. In a note to the French Academy of Sciences, read August 1, 1881, he said: "The recent improvements made in dynamo-electric machines have given me the idea of employing them for the directing of balloons, combined with secondary batteries, which although of relatively light weight, store up a large amount of energy. Such a motor, connected by a propelling screw, offers advantages over all others, from an aerostatic standpoint. It operates without any fire, and thus prevents all danger from that element under a mass of hydrogen. It has a constant weight, and does not give out products of combustion which continuously unballast the balloon and tend to make it rise in the air. It is easily set running by the simple contact of a commutator." M. Tissandier carried out these ideas in a model with which he experimented publicly and successfully at Paris, during the electrical exhibition of 1881. He then went to work with a balloon equipped with a light Siemens machine and a bichromate of potash battery, and resolved to try the principle of screw propulsion. Finally, in October, 1883, he made a notable experiment near Paris with a balloon having a total weight of 1,240 kilogrammes. Allowing 10 kilogrammes, the lifting force was 1,250 kilogrammes. The bichromate

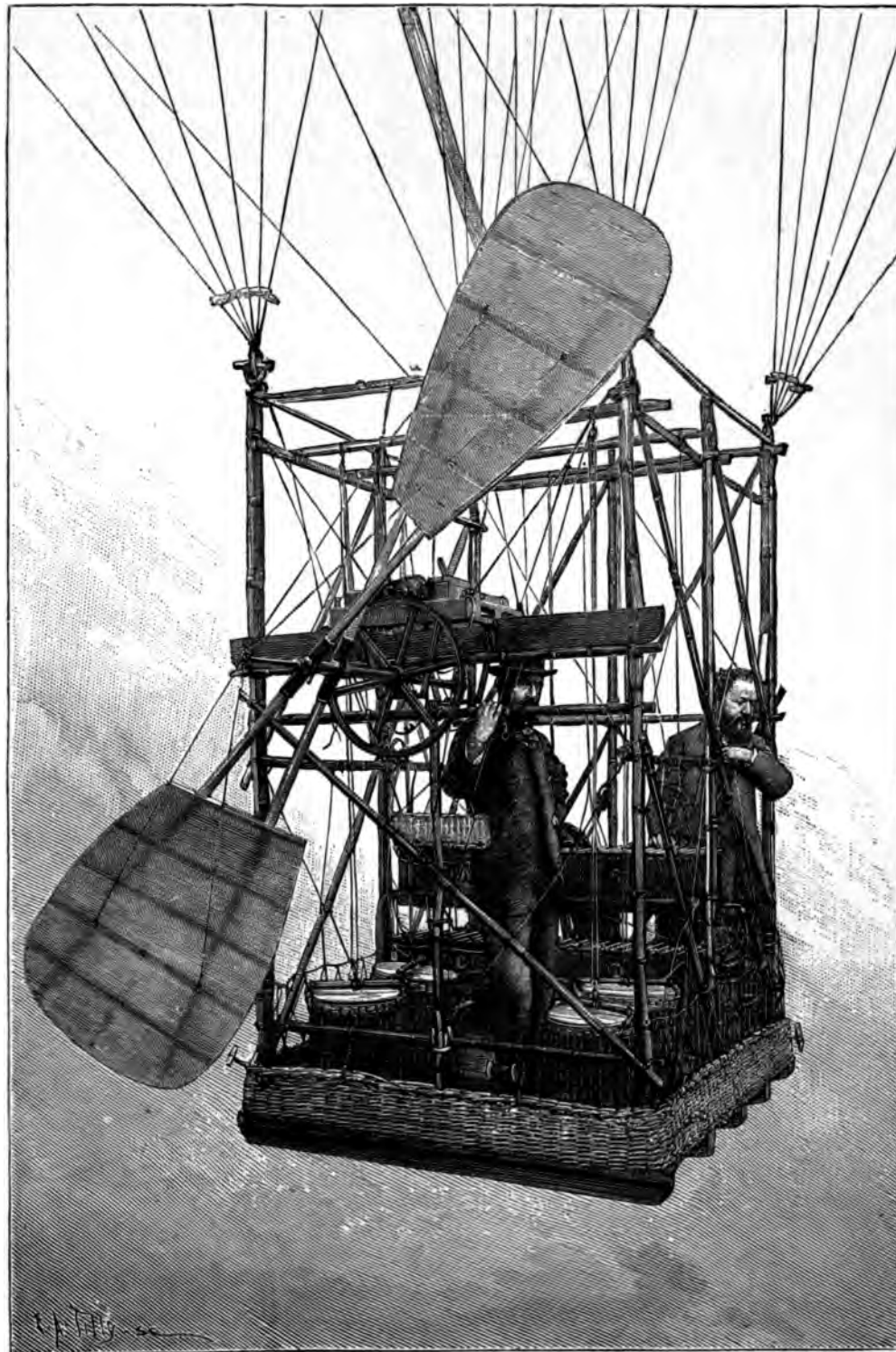


FIG. 139.—VIEW OF THE TISSANDIER BALLOON.

of potassium batteries were composed of four troughs with six compartments, making twenty-four elements in circuit. By means of a mercury commutator, 6, 12, 18, or 24 elements could be used, thus giving four different speeds of the screw, varying from 60 to 180 revolutions per minute. The results of this experiment were summarized by M. Tissandier as follows:



FIG. 140.—BATTERIES OF TISSANDIER BALLOON.

“We have concluded from this first trial that:—1, electricity furnishes a balloon with the most convenient power, the management of which in the car is remarkably easy; 2, in our own case, when our screw, 2.8 metres in diameter, made 180 revolutions per minute, we were able to keep head to wind, moving three metres per second, and, when proceeding with the current, to deviate from the line of the wind with great ease; 3, the mode of the suspension of a car from an elongated balloon by means of bands running obliquely and supported by flexible side-shafts, insures perfect stability to

the whole.” Our illustrations, Figs. 139 and 140, give an excellent idea of the appearance of the balloon and of its motive mechanism. The length of the balloon was 28 metres, and its diameter at the centre 9.2 metres. The Siemens motor, which weighed only 54 kilogrammes, had an armature very long in proportion to its diameter, and which made 1,800 revolutions while the screw to which it was geared made 180.

The speed obtained in 1883 was three metres per second. During a trip made by the Tissandier brothers in 1884 a speed of nearly four metres was obtained, and it was also found that the balloon could be brought back to its starting point even in calm weather. The next noteworthy experiments in this direction were those of Capt. Renard and Capt. Krebs, who on August 9, 1884, made a highly successful demonstration with their directible balloon, the outcome of six years' quiet work, and of a grant of 100,000 francs from the French government. The shape of the balloon was not unlike that of a cigar pointed at both ends. The car suspended by network contained seats for two aeronauts, the motive power, and the steering apparatus. Capt. Renard invented for this trial a secondary battery of unusual lightness, and Capt. Krebs devised the screw and rudder, and the motor gearing. The dimensions and weights were these:

Length of the inflated ellipsoid, . . . 50 m. 42 cent.
 Central diameter, 8 m. 40 cent.
 Volume, 1,864 cub. m.
 Length of car—Nacelle, 33 m.

Weights:

Balloon and ballonet, 869 kilos.
 Silk covering and net, 127 kilos.
 Car complete with rigging, etc., . . . 152 kilos.
 Rudder, 46 kilos.
 Screw-propeller, 41 kilos.
 Motor, 98 kilos.
 Wheelwork, 47 kilos.
 Shaft, 30 kilos. 500 grams.
 Battery complete, 435 kilos. 500 grams.
 Average velocity per second, 5 m. 50 cent.
 Diameter of the propeller, 7 m.
 Number of revolutions per minute, 30 to 40
 Number of elements employed, 32

The electric motor was constructed to develop 8.5 horse power upon the shaft, and it trans-

mitted its motion thereto by means of a pinion gearing with a large wheel. The battery was divided into four sections, that could be connected either for quantity or for potential, and was calculated to deliver 12 horse power—8,952 watts—to the motor for four consecutive hours. The trip was made in the neighborhood of Paris. In his official report to the Academy of Sciences, M. Hervé Magnon said: "The balloon rose to an elevation of fifty metres above the ground, at which elevation it was kept per-

the balloon descended gradually, obliqued right and left, forward and backward, at the pleasure of its pilots, and finally landed exactly at the point indicated." The time occupied in making the entire circuit of 7,600 metres (about five and one-half miles) was only twenty-three minutes. The maximum velocity obtained was nineteen kilometres per hour. In later trips an average velocity of twenty-five kilometres was shown as the result of the various improvements in details. Here, then, was the

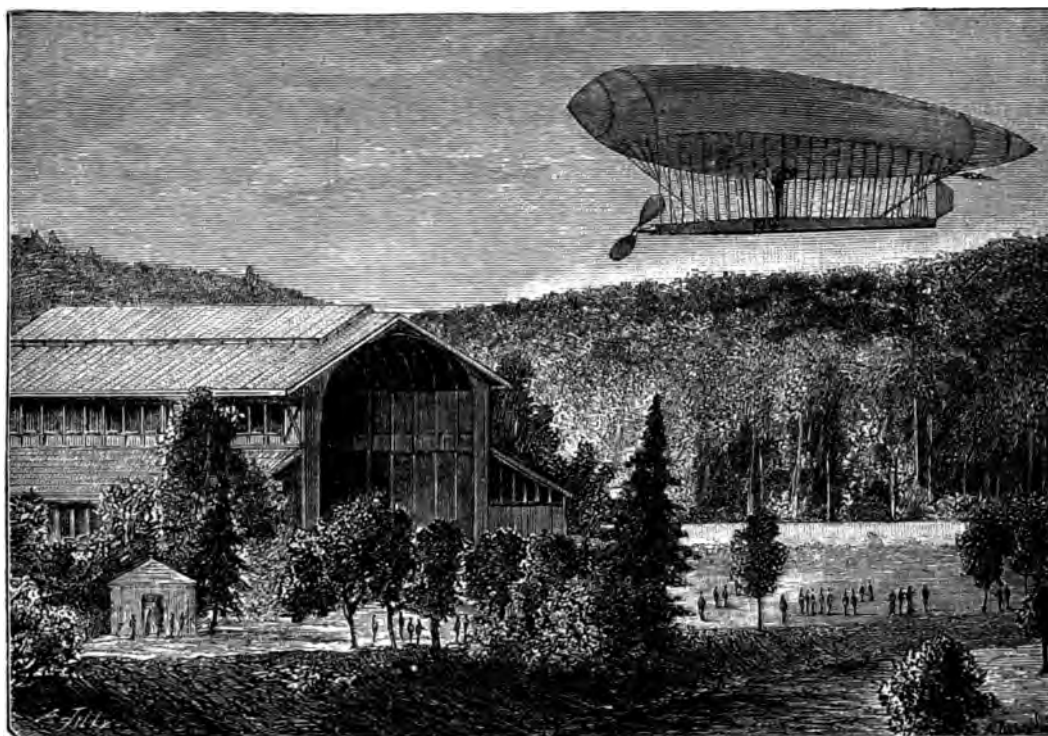


FIG. 141.—THE KREBS-RENARD BALLOON.

manently by Capt. Renard, Capt. Krebs manoeuvring the rudder. As soon as the propeller was given a rotary movement the aerostat took its course toward the Hermitage of Villebon, which, previous to the ascension, had been designated as its objective. The wind at this moment moved with a velocity of five metres per second, and the balloon moved against it. So soon as arrived at its destination the officer who held the tiller waved a flag, the signal of return, upon which we saw the aerostat luff, describe majestically a half circle of a radius of about 300 metres, and sail back to Meudon. Upon reaching the lawn, whence it had started,

attainment of practical ballooning. As Col. Fred Burnaby, an enthusiastic aeronaut, had said but a short time before in discussing the availability of electricity, "to put the case in a nutshell, aerial navigation is a mere question of lightness and force," and the two French officers had undoubtedly succeeded in putting weight and strength in their right proportions to be effective. M. Gaston Tissandier, whose ample experience qualified him to speak authoritatively on the subject remarked, not only with generosity but with truth: "These new experiments are decisive. Navigation of the air by means of long balloons provided with

screws, is demonstrated. We will repeat what we have already said many times, that to be practicable and useful, aerial ships must be very long, of very large dimensions, which shall carry very large machines capable of giving a speed of from twelve to fifteen metres a second, allowing their working at almost any time. When the wind is high, or there is a squall or tempest, aerial ships must remain in port, as other vessels do. It becomes now only a question of capital."

A view of the Renard-Krebs balloon described in the above passages is given in Fig. 141, which shows also its starting place.

CHAPTER XI.

TELPHERAGE.

WHILE in the electric railway, as in electric lighting, the tendency of inventors has been to preserve old forms and methods, for the purpose of more easily adapting their devices to public use, in what is known as "telpherage" a decidedly new departure is taken. Mr. Herbert Spencer, if we remember aright, once drew attention to the survival of conventional curved lines in the bodies of the English railway cars, which thus present the aspect of the old and obsolete stage coaches; and we might instance the more recent case of incandescent lighting, in the introduction of which to general notice and use, Mr. Edison sought as far as possible to adhere to methods that had become familiar in the employment of gas. His mains, branches, meters, brackets, "electroliers," and switches are, practically, so many like parts of a gas-lighting system, and may be safely left to the handling of the most inexperienced; only the generating apparatus requires technical skill and knowledge on the part of those who deal with it. Some may say that telpherage is after all simply an old idea, plus electricity, but we believe that to the vast majority of people, the transmission of freight or passengers, along a wire road, is a surprising innovation, an application for which their information or experience can find no parallel.

The word "telpherage" was coined by the late Professor Fleeming Jenkin, who conceived the invention now being developed by Professors Ayrton and Perry. In a lecture before the University of Edinburgh, Professor Jenkin said: "The transmission of vehicles by electricity to a distance, independently of any control exercised from the vehicle, I will call 'telpherage.' The word should, by the ordinary rules of derivation be 'telphorage,' but as this word sounds badly to my ear, I ventured to adopt such a modified form as constant usage in England for a few centuries might have produced; and I was the more

ready to trust to my ear in the matter, because the word 'telpher' relieves us from the confusion which might arise between 'telephore' and 'telephone' when written."

Generically considered, a telpher line system consists of a rod or rail track of considerable length, suspended several feet from the ground, connected with a source of electricity placed at some suitable and convenient place at or near the course of the track, and

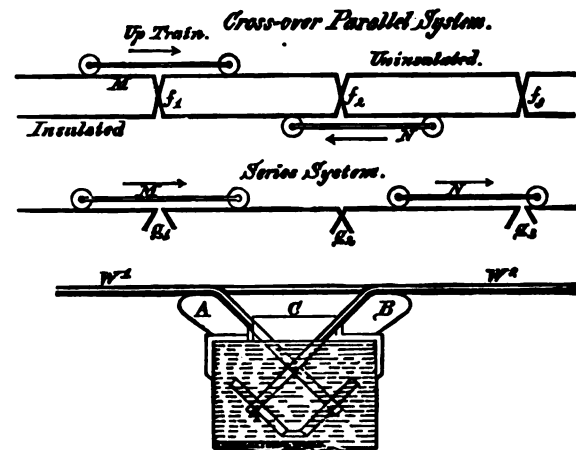


FIG. 142.—DIAGRAM OF TELPHERAGE TRACKS.

traversed by an electro-locomotive which derives its motive power electrically from the said track, draws a number of small holders of freight or passengers, and is controlled, as to its motion, from a place or places other than itself.

A telpher line can be built on either the "series" or the "cross-over parallel" system. Figs. 142 and 143 show the "series" system as put into experimental operation at Weston, Hertfordshire, England, about two and a half years ago. M and N are two trains of cars running on the line upon which the wheels bear. The line has make-and-break mechanism at g_1 , g_2 , g_3 , points about 120 feet apart.

These make-and-breaks are normally closed, so that a current of electricity may flow from end to end. But when an electric train is started over the line, say from left to right, as the forward wheel of the motor strikes the make-and-break g_1 , it opens the circuit by moving the latter; and then the current takes the course through to the rear wheel of the train, the motor thus receiving the current that energizes it. The train is made a little longer than the

train receives no current. It is clear that any desired number of trains may be run upon the line at one time, it being necessary only to have the electromotive force adapted to the number of trains operated. In the larger illustration of the series system, the rough posts carry cross-arms securely bolted to them. On the overhanging ends of these arms, are the junction blocks for the ends of the sections. These junction blocks are placed only on alternate

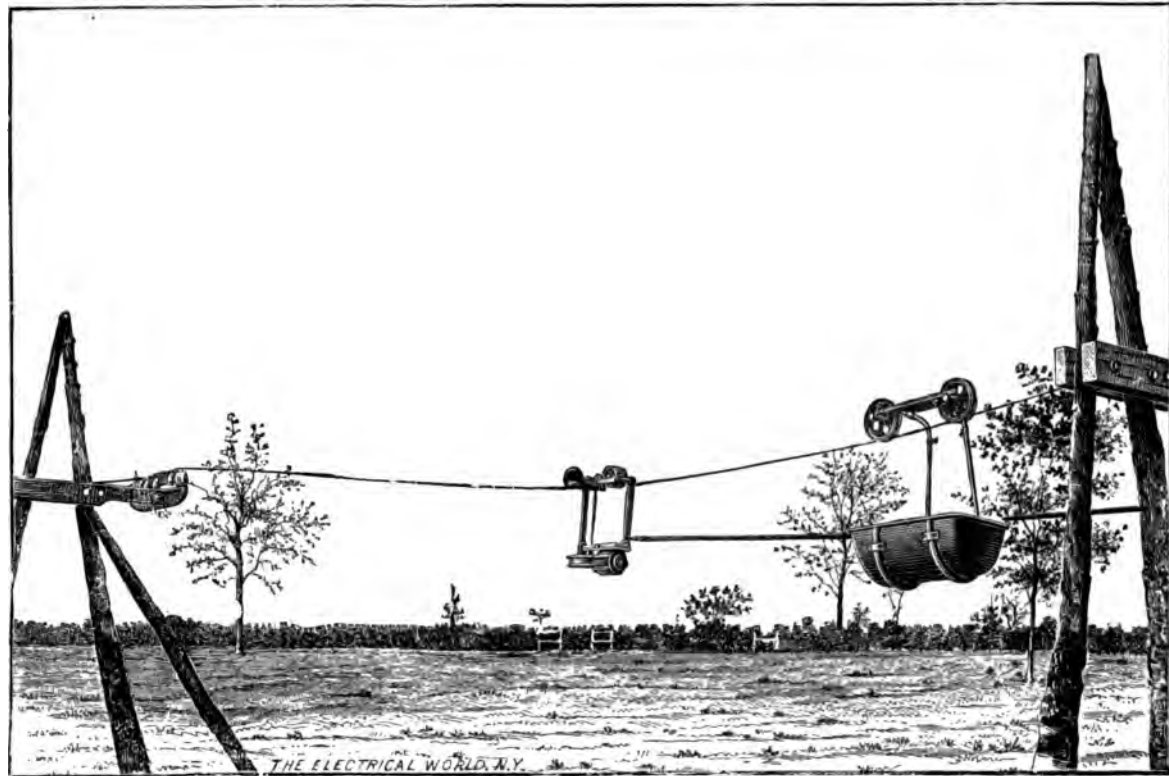


FIG. 143.—VIEW OF "SERIES" TELPIER ROAD, WESTON, ENGLAND.

120 feet between breaks, so that when the forward wheel strikes break g_2 , though it opens the circuit there, the current still flows through the train, spanning the section of the line from g_1 to g_2 . But when the rear wheel of the train strikes the break g_1 , it closes it, so that current may still flow through the line and train. As the train moves onward, it successively opens the line circuit by the "break" under its foremost wheel, and closes the line circuit by the "make" under its rearmost wheel, so that the current for the motor is derived from the sections of the track under the forward and rear wheels of the train, at which time the track immediately under the

posts, because the posts are 60 feet apart, and the sections of the line are 120 feet in length. The intermediate posts carry only suitable supports for the line. Fig. 142 represents one of the junction blocks. Cast-steel supports A and B are bolted down on a wooden block, which is in turn bolted to the ends of the cross-arms; or this block may be the end of the cross-arm itself. The upper surfaces of A and B are channelled to receive the conductors W^1 and W^2 . These conductors pass one on each side of the cast-steel piece C , and go through holes in the wooden block, being secured in the latter by nuts, as shown. The piece C is bolted on the wooden block in a position intermediate

between A and B , but is insulated from them. This piece serves as a continuation between the rods W^1 and W^2 so that the wheels of the locomotive and skips can ride from W^1 to W^2 with regularity and smoothness. The circuit is completed either by ground, a conductor for the purpose, or, preferably by a return line over which the locomotive may run. The wire in this line is five-eighths of an inch in diameter. The load is carried in seven skips, the first being seen in Fig. 143. About half a ton can be put into each skip and a speed obtained of six miles an hour.

is supported by what is practically one long, continuous steel rod; but, in reality, at the tops of the posts the rods are electrically subdivided into sections and joined across by insulated wires, one of which can be seen on the post in the foreground of Fig. 144, which gives a good idea of the line in actual operation. To prevent the metallic wheels of the skips from short-circuiting the two sections as they cross the tops of the posts, there are insulated gap-pieces, also to be seen in Fig. 144, at the tops of the posts where the steel rod is electrically divided. It is found that for moderate inclines,

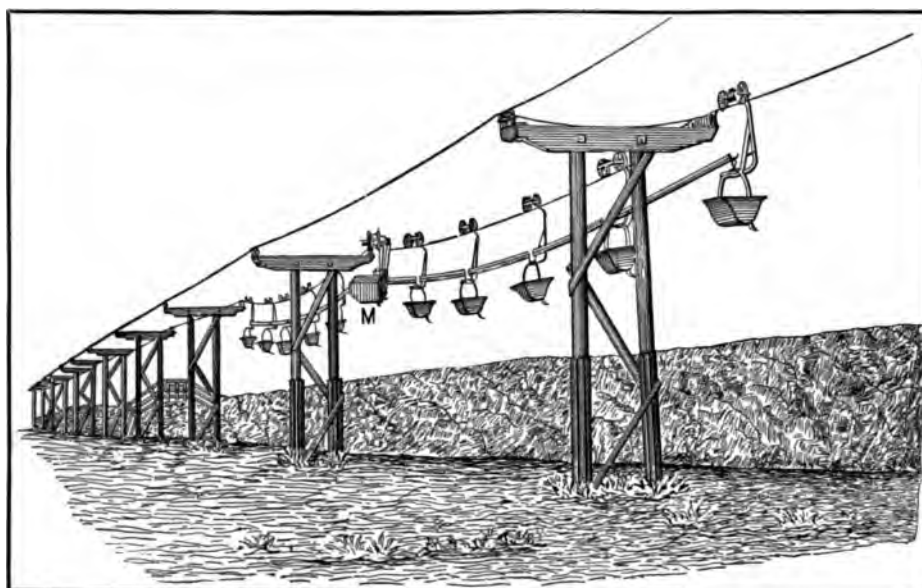


FIG. 144.—VIEW OF "CROSS-OVER PARALLEL," TELPHER ROAD, GLYNDE, ENGLAND.

The principle of the cross-over parallel system of telferage is best shown forth in a commercial line—Fig. 144—recently put in operation at Glynde, England, for the New Haven Cement Company, to carry clay from a pit to the Glynde railway siding, whence it is delivered into trucks and taken by rail to the cement works. Fig. 145 illustrates the construction of the track for two trains. D is the dynamo furnishing current to the circuit A_1 and B_1 , respectively, positive and negative. The wheels, L and P of one train and L_1 and P_1 of the other are insulated from their trucks and connected in the case of each pair by a wire on the motor. Consequently as the trains move, a current is always passing from a positive section of the line to a negative section through each motor. Mechanically, each train

direct driving with pitch chains, of two wheels with india rubber treads, gives a gravitation grip sufficiently strong for haulage purposes. In the earlier lines, Ayrton and Perry motors were used; in this, the Reckenzaun has been tried.

The automatic governing of the speed of the train is effected in two ways,—first, there is a governor attached to each motor, which interrupts the electric circuit, and cuts off the power when the speed becomes too high; secondly, there is a brake which is brought into action should the speed attain a still higher value. To avoid the formation of a permanent electric arc when the circuit is broken, the governor (Fig. 146) is so arranged that the diverging weights are in *unstable* equilibrium between two stops: they fly out at about 1,700

revolutions per minute of the motor, and fly back at about 1,600. When the circuit is closed, the current is conveyed across the metallic contact at *C*. When the weights *W W* fly out, this contact is first broken, but no spark occurs,

In this line which has now been working for nearly a year, the steel rods are three-fourths of an inch in diameter and are supported on wooden posts about eighteen feet high, at either end of the cross-piece, which is eight feet long.

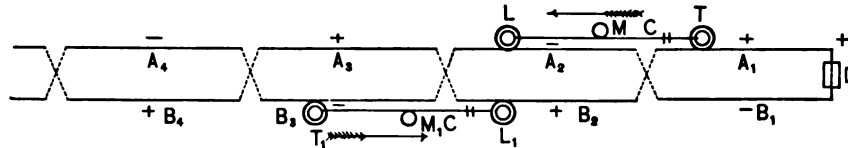


FIG. 145.—DIAGRAM OF GLYNDE TRACK.

because a connection of small resistance is continued at *B* between the piece of carbon and a piece of steel, which, being pressed out by a spring, follows the carbon for a short distance as the arm *A* begins to fly out. This contact is next broken, producing an electric arc; which,

The skips are trough-shaped. Each holds about two hundred weight, and is suspended from the line by a light iron frame, at the upper end of which is a pair of grooved wheels running on the line of rods. Ten of these skips, five each side of the motor, make up a train. At the charging end of the telpher line, the skips are loaded each with about two hundred weight of clay, the train thus carrying one ton. A laborer, by touching a key, starts the train, which travels at a speed of from four to five miles an hour along the overhead line to the Glynde station. Arrived there, another laborer upsets each skip as it passes over a railway truck, into which the clay is thus loaded. This upsetting, however, will eventually be performed automatically by means of a lever on

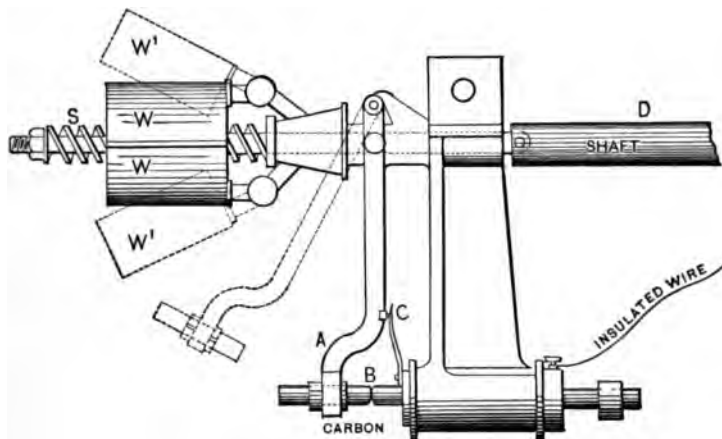


FIG. 146.—TELPER GOVERNOR.

however, is instantly extinguished by the lever *A* flying out to the dotted position. The brake is shown on Fig. 147, and consists simply of a pair of weights, *W W*, which, at a limiting speed greater than 1,700 revolutions per minute of the motor, press the brake-blocks *B B* against the rim *C C*, and introduce the necessary amount of retarding friction. In practice, however, with the gradients such as exist at Glynde, and which do not exceed one in thirteen, the economic method of cutting off the power automatically with the governor is all that is necessary to control the speed of the train, the brake rarely coming into action. With steeper gradients, the brake would be of more service.

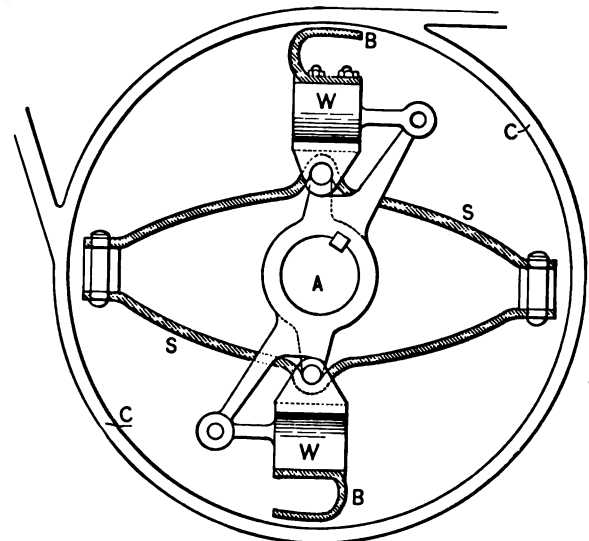


FIG. 147.—TELPER BRAKE.

each skip, which will come in contact with a projecting arm as it passes over the truck.

The laborer at the discharging end of the line has full control over the train, and can stop, start, and reverse it at will, as can also the man at the other or loading end. There are two trains at Glynde, but only one is at present

\$6,000, that sum including outlay for an equipment to consist of stationary steam engine, generating dynamo, and five trains with electro-locomotives, with a capacity to carry over a hundred tons daily. The total cost of operation is put at six cents per ton of material carried. The figures of the Telpherage Company

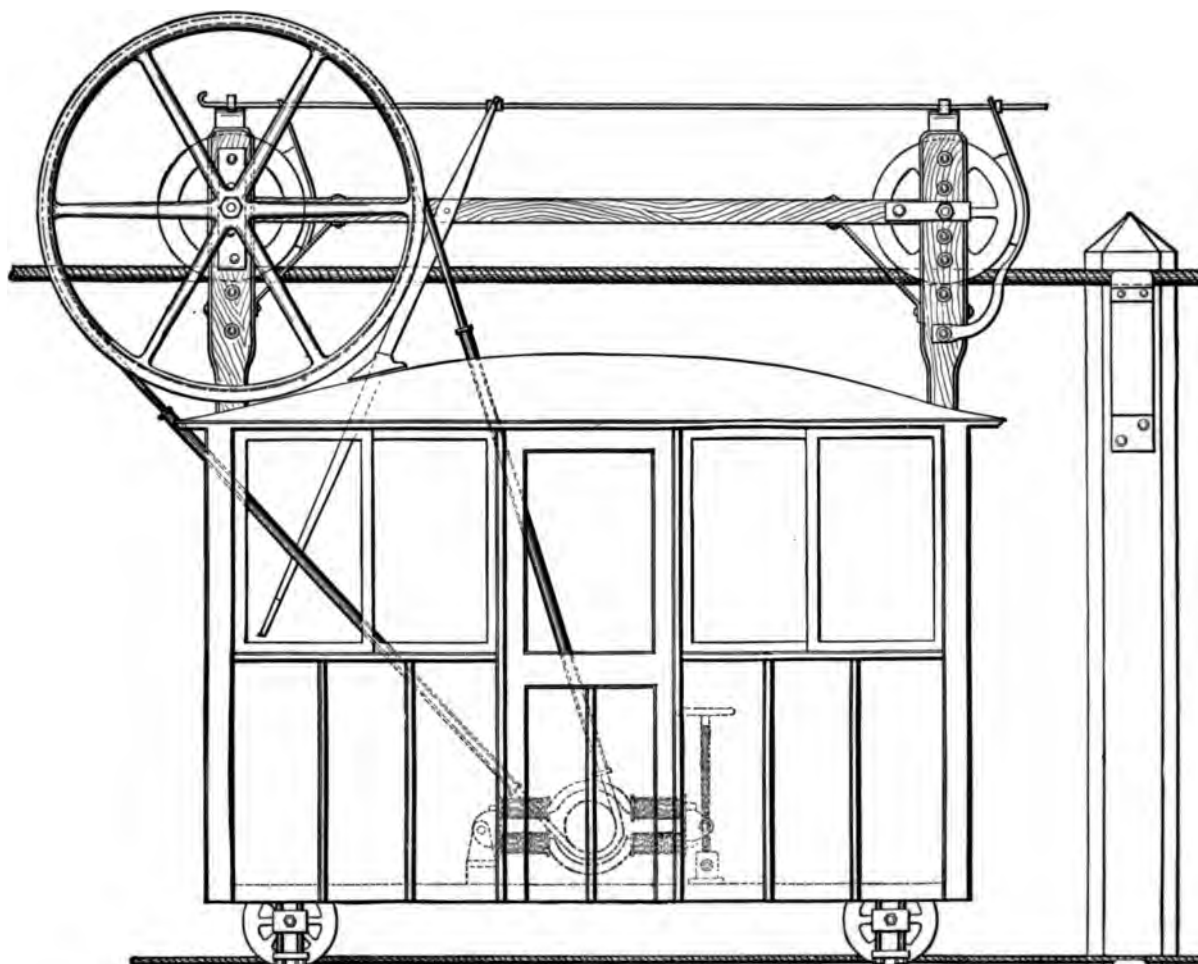


FIG. 148.—CHANDLER SYSTEM OF SUSPENSION TRANSPORTATION—ELEVATION OF LOCOMOTIVE CAR.

used, that being found sufficient to deliver 150 tons of clay per week at the station. The trains need no attention when running, as they are governed to run at the same speed both on rising and falling gradients. An automatic block system is provided, so that as many as twenty trains can be run on the line without the possibility of collision.

As a few figures in regard to expense will be interesting, it may be stated, that such a telpher line as that at Glynde can be put up for

of London show a cost of about \$50,000 for a line ten miles long, to carry 30,000 tons of freight yearly. It need hardly be pointed out that such lines can be made important feeders for main lines of railway. To quote once more from the modest but brilliant electrician, the late Professor Jenkin, whose ideas have been carried out by his associates, Professors Ayrton and Perry:

“Mineral traffic is only one small part of the work which these lines can do. Where rail-

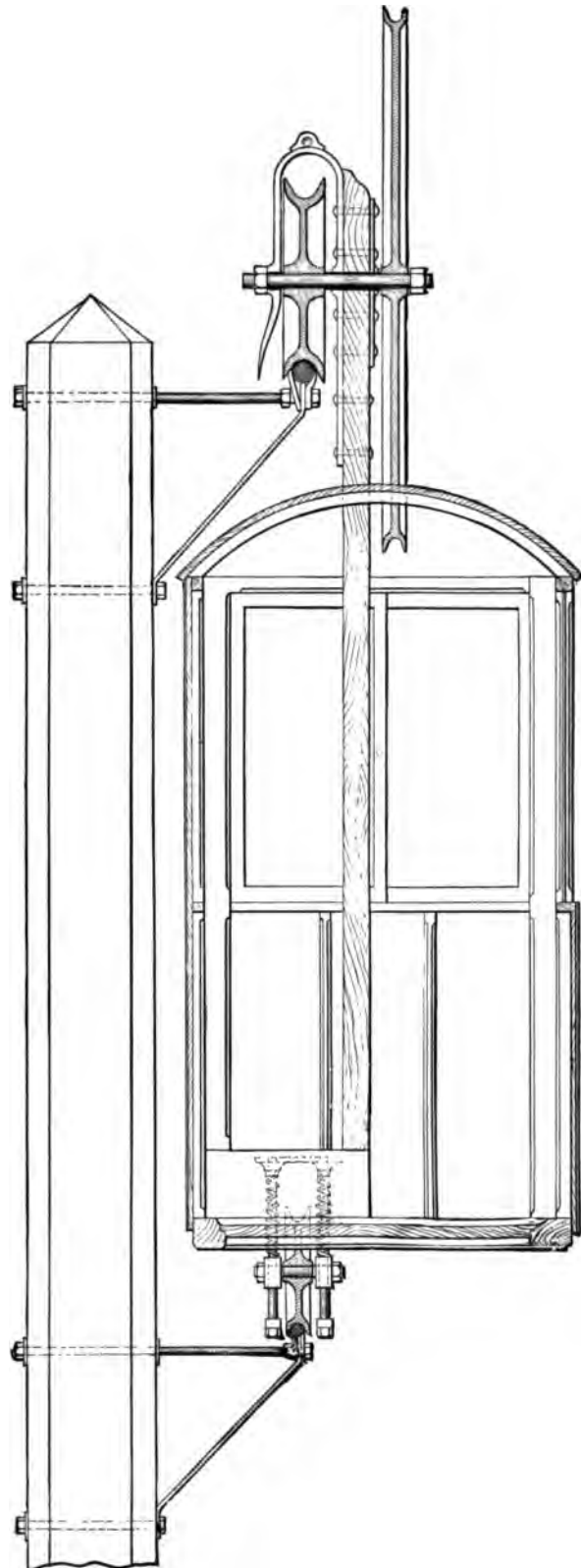


FIG. 149.—CHANDLER SYSTEM OF SUSPENSION TRANSPORTATION—END VIEW OF CAR.

ways and canals do not exist, telpher lines will provide the cheapest mode of inland conveyance for all goods—such as corn, coal, root crops, herrings, salt, bricks, hides, and so forth—which can be conveniently subdivided into parcels of one, two, or three hundred weight. In new colonies the lines will often be cheaper to make than roads, and will convey goods far more cheaply. Surely I am not too sanguine in expecting that great changes will be produced in agriculture by these new facilities for trans-

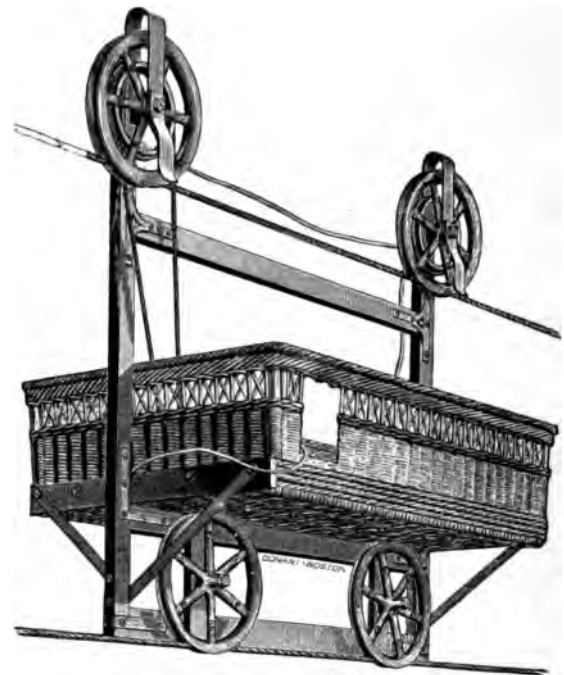


FIG. 150.—SMALL FREIGHT CAR, CHANDLER SYSTEM.

port, coupled with the delivery of power at will from any point of the telpher road. It must not be supposed that I look on the new telpher lines as likely to compete with railways or injure their traffic. On the contrary, my feeling is that they will act as feeders of great value to the railways, extending into the districts which could not support the cost even of the lightest railway. It is idle to endeavor to foretell the future of any new idea; but this much is certain—a novel mode of transport, offering some exceptional advantages, will be publicly shown on a practical scale to-day."

A system of this nature, for transporting freight and passengers, is now being introduced by the Suspension Transportation Company, of Boston, under various patents, covering

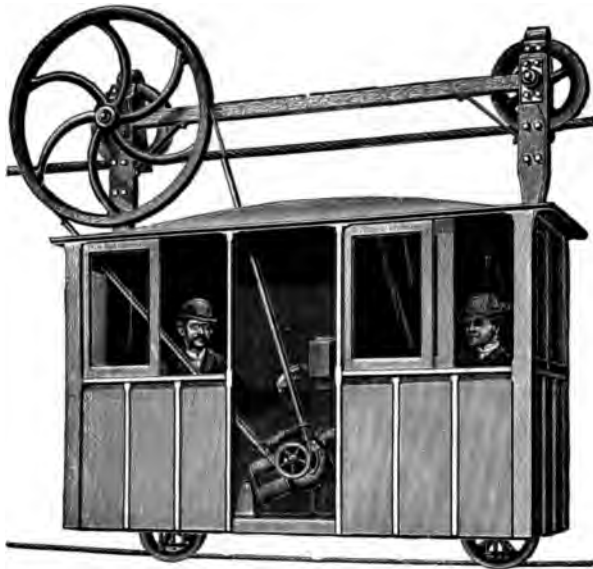


FIG. 151.—MOTOR ON CHANDLER WIRE ROAD.

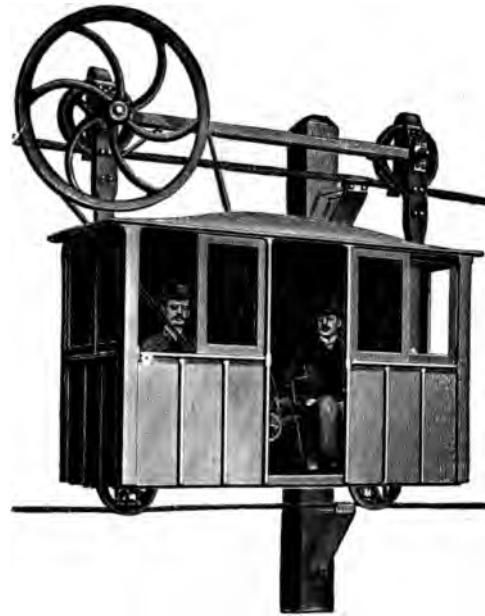


FIG. 152.—PASSING A POLE ON CHANDLER WIRE ROAD.

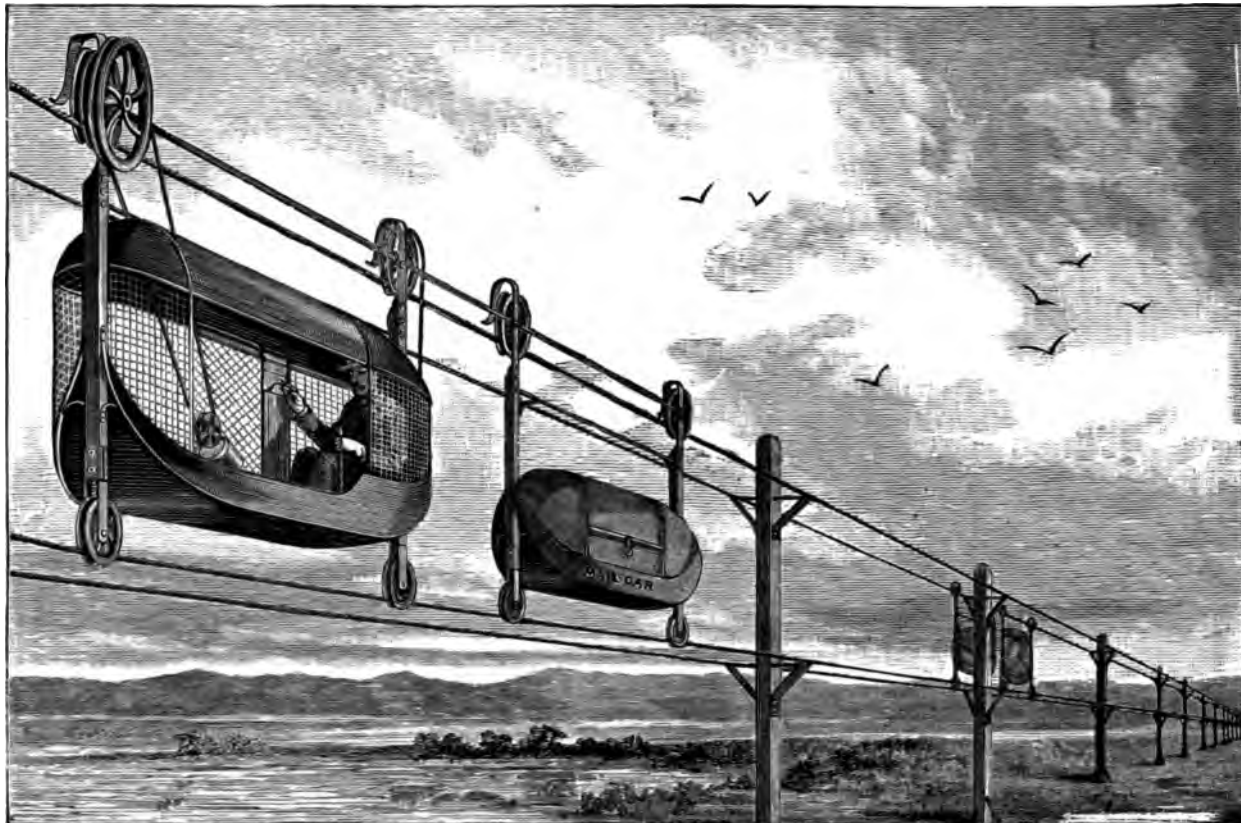


FIG. 153.—DESIGN FOR MAIL OR COAST SERVICE.

the use of electricity, steam, or other motive power for aerial transportation.

The general *modus operandi* of this company's system for an electric wire road is well

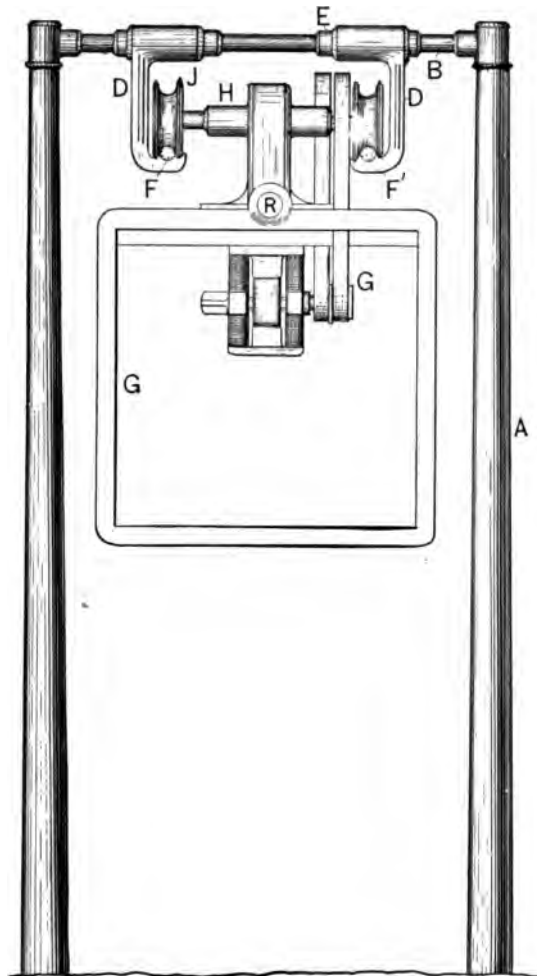


FIG. 154.—VAN DEPOELE TELPHER SYSTEM.

illustrated in the accompanying engravings. It is evident that such a system, while not interfering with the cultivation of the soil or with pasturage, is free from danger to man and beast, and that a mere right of way is sufficient without the cost of the fee. Again, it requires no cuttings or fillings, and is thus adapted to uneven, rocky, or uncleared land, and the turning of sharp curves presents no obstacles. In crossing streams no bridges need be used. The opportunities for the application of this system are vast, and the variety of uses to which it can be put is very great, both in cities and in the country.

An experimental line of this character, with a capacity for transporting several tons in weight upon the cables, is now in successful operation at the works of Mr. Leo Daft, and the details of the system will prove interesting.

The posts that carry the cables are placed thirty feet apart, and the cables are supported upon wrought-iron brackets bolted to them. The cables rest upon rubber strips placed in clamps at the end of the braces. This is clearly shown in Figs. 148 and 149, which represent the locomotive in elevation and in section as it appears suspended between the cables. The latter are of steel, the upper being two inches in diameter and the lower one inch. These are placed in the same vertical plane and are seven feet six inches apart. The current passes from the upper to the lower cable, the motors being in parallel or multiple are between them. The motor within the car is geared to a large wheel mounted upon the same shaft with the forward grooved traction wheel, and is pivoted on one end, so that all slack in the belt may be readily taken up. The braking will be accomplished by electrical means, but hand brakes are also provided as shown, which can be applied through the medium of the long lever entering the car, the other end of the lever being attached to the rod connecting the brake-shoes on the two wheels. Two safety catches are attached to each car and are placed

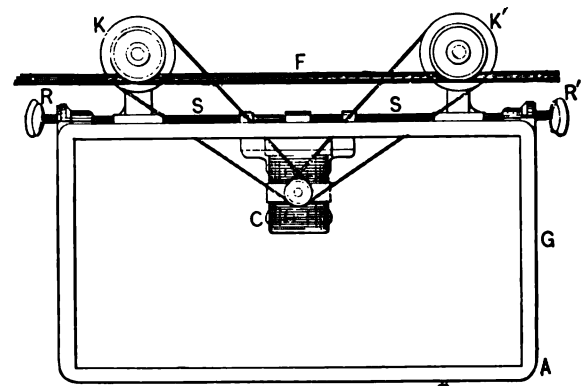


FIG. 155.—VAN DEPOELE TELPHER SYSTEM.

alongside the upper wheels. They prevent the car from leaving the cable in case of a running off of the wheel.

In all places where the grade is much above ground it is proposed to stretch a safety wire from bracket to bracket, thus insuring against accident.

The system is evidently adapted not only for the transportation of goods but for passenger traffic. The rate of speed will depend on the service to be rendered; as high as twenty-five miles an hour, and even more, is spoken of.

Fig. 150 shows the small "freight express" car operated successfully for several weeks at the Novelties Exhibition in Philadelphia last year. Figs. 151 and 152 illustrate the section of track now in use experimentally at the Daft Works, Greenville, N. J. The illustrations are made from photographs, and show accurately the slight sag in the wire caused by the passage of the car, weighing one ton. Fig. 152 shows the manner in which the car is enabled to pass the poles on the line. The car seen carries a small Daft motor taking its current from the wire cable.

Fig. 153 is an illustrative design embodying a plan proposed by the company to be adopted for mail service or for life-saving service along the coast. There can be no question that the use of such a device would immensely expedite the

mail delivery between New York and Brooklyn, for example, or could be applied in the transportation of mail bags from the general post-office to the Grand Central Depot. The saving in time alone would be worth a great many thousand dollars annually.

The "telpher" system devised and patented by Mr. C. J. Van Depoele, has been in operation for some time at the factory of his company in Chicago. The method adopted by Mr. Van Depoele consists in suspending the car upon two cables supported by pillars and cross-bars, as shown in the accompanying illustrations, Figs. 154 and 155, which represent respectively a front and a side view of the arrangements. The hangers *D*, which support the cables *F F'*, are insulated, and the cables themselves form the positive and negative terminals of the motor. The band wheels *K K'*, are connected with the driving wheels of the electric motor *C*. Buffers *R R* are also provided at the ends of the rods *S S*, the inner ends of which are provided with buffer springs.

CHAPTER XII.

LATEST AMERICAN MOTORS AND MOTOR SYSTEMS.

SINCE the foregoing chapters were written and prepared for press—almost entirely as they now appear—phenomenal activity has been displayed in America in the production of new motors and motor systems. It has therefore been thought well to bring the work down to

some time been employed in the running of light machinery, especially sewing machines, and it is said that not less than a thousand of these are in actual service to-day.

The motor, which we illustrate in the engraving, Fig. 156, is enclosed within a case, one end of which is removed so as to expose the interior. The magnets are of the converging, consequent pole type, and form an integral part with the top and bottom of the casing. The two sides are cast separate and held together by screws.

The armature, or more correctly the armatures, for there are two of them, are shown in Fig. 157. As will be seen, they are of the Siemens shuttle-wound type, and are placed at right angles to each other. The commutator has four segments and the terminals of the wire on each armature are connected to opposite segments. The latter are not made parallel with the spindle, but are helical in shape, so that there is no break in the circuit at that point, since the brush passes the current to one armature before leaving the other. By this arrangement only one armature is in action at one time. Taking the one to the right, for example, it is at its maximum

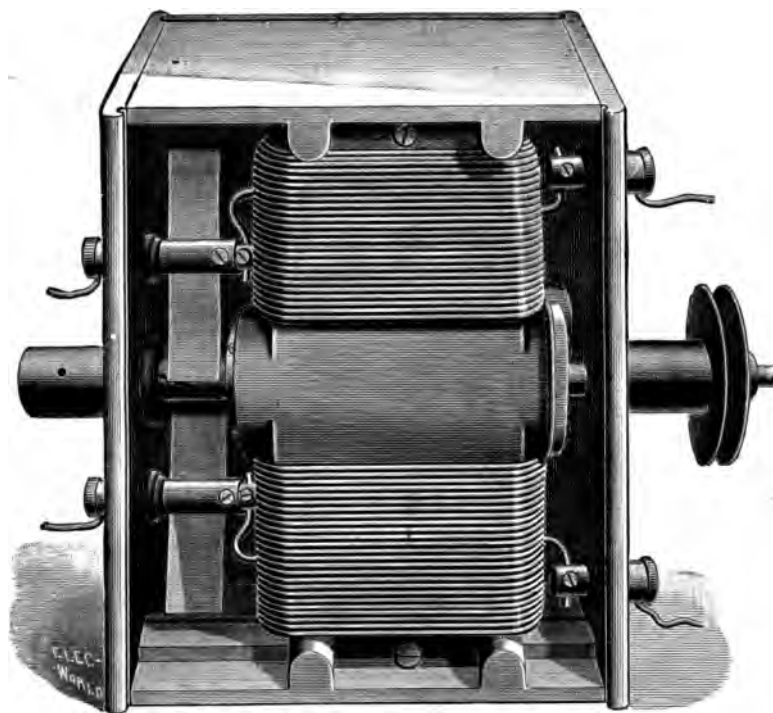


FIG. 156.—THE STOCKWELL MOTOR.

date by including all the latest developments in the motor field. This chapter should be read in connection with, and as supplementary to, Chapters VII. and IX.

At the meeting of the National Electric Light Association, held at Detroit, in August, 1886, the interesting fact was brought out that more than 5,000 electric motors of all sizes were in operation in this country at the present time. Among those mentioned as being largely in use was the Stockwell motor, which has for

effect during the quarter revolution, when the polar faces of the armature are approaching the pole-pieces, and until they come directly opposite each other. During the next quarter revolution the armature is cut out of the circuit entirely; on the third quarter it again comes into the circuit until occupying the same relative position as in the first quarter; and, finally, in the fourth quarter it is again cut out. But it is evident that during each of these idle periods of the armature to the right,

that to the left comes into circuit and goes through relatively the same cycle of operations. The action is quite analogous to that in two steam engines coupled with their cranks at right angles to each other. While one is passing over the centre, and practically doing no effective work, the other is in the position of

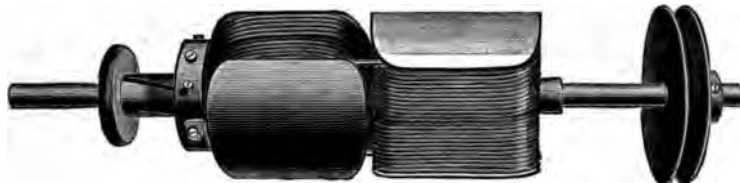


FIG. 157.—ARMATURE OF STOCKWELL MOTOR.

maximum power, with the crank at right angles to the line of stroke. In both cases, there can be no dead point, and the motion is smooth and continuous.

Where motors are applied to machinery required to be run at different speeds, some method of regulation becomes necessary, and in the present instance this has been worked out in a very simple manner. Where the mo-



FIG. 158.—PERSPECTIVE OF RESISTANCE BOARD.

tors, as usual, are connected in series with each other, an adjustable resistance is provided which is contained within a box, such as that shown in perspective in Fig. 158, and in section in Fig. 159. This adjustable resistance is placed in a shunt to the motor and consists of a series of carbon bars of gradually decreasing conductivity. As the switch lever is passed over

the successive contacts, increasing resistances are introduced in the shunt, which consequently allows more current to pass into the motor and increases its speed correspondingly. The spring attached to the switch lever keeps the latter in the position of "no current" in the motor, and by attaching a cord or other device connected to a treadle, the operator on a machine has both hands free to work with.

The carbon resistance bars are copper-plated at their ends and firmly clamped, and by making them of gradually decreasing cross-section, a relatively greater increased resistance is thrown into the circuit as the switch lever passes from one contact to another. A wide range of control is therefore afforded with a comparatively limited movement of the

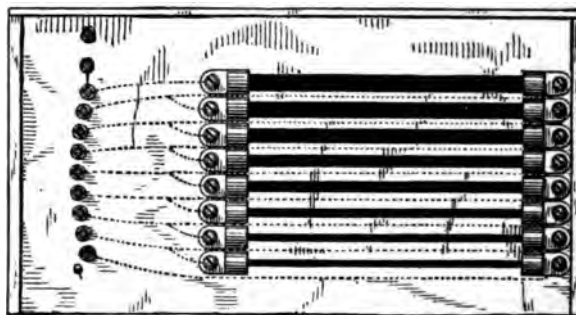


FIG. 159.—DIAGRAM OF RESISTANCE BARS.

lever. The motor is provided with a clamp, so that it can be readily attached to a table or work bench.

The varying loads which in practice are thrown upon an electric motor driving a number of machines, require that some provision be made for keeping the speed constant under each change of condition. Mr. John Beattie, Jr., of Westport, Mass., in solving the problem employs a motor whose field magnets are provided with several independent coils upon each leg, as shown at *C*, Fig. 160. Geared to the motor there is a governor, *D*, which oscillates a lever *K'* having a circular rack *M* at its extremity. The latter swings a lever *K*, which touches both the terminals *L* of the field-magnet coils, and those of a corresponding number of resistance coils *I*, at *L'*. The lever *K*, as shown, is in series with one or more of the field-magnet coils which are in parallel circuit and

with one or more of the resistance coils, which are also in parallel circuit.

It will now be readily understood that any increase of speed in the motor operates so as to

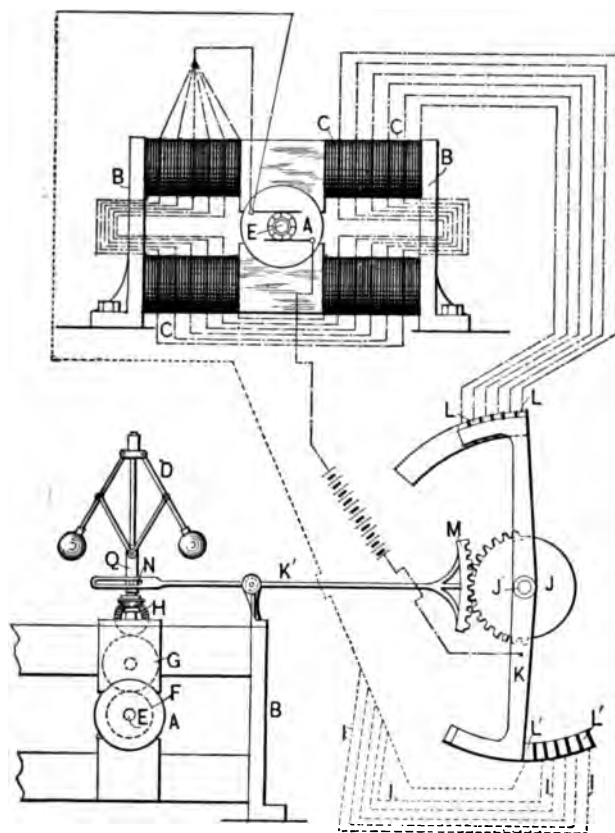


FIG. 160.—BEATTIE MOTOR.

cause the substitution of one or more of the resistance coils for a like number of field-magnet coils. This of course reduces the strength of the field and reduces the speed of the motor to its normal amount.

The armature of the motor employed by Mr. Beattie is provided with two sets of grooves, Fig. 161, $P P'$, parallel with the armature shaft, and at right angles to these run a series of deep annular grooves Q . The wires are wound according to the method of Siemens.

Recognizing the growing importance of the electric motor in the field of applied electricity, Mr. C. F. Brush has for some time past devoted his attention to the construction of a motor which should fulfil the conditions required in a successful prime mover. Steadiness of power and constancy of speed under all loads are two of the principal objects to be sought

for, and in the new motor these have been provided in a very ingenious way.

The motor, which is illustrated in the engraving, Fig. 162, closely resembles the Brush dynamo, which is too well known to require extended notice; but the devices added to the machine for the purpose of securing the advantages above mentioned are decidedly interesting, and merit a detailed description.

It will be seen that, mounted on the shaft between the commutator and the journal bearing, there is a cylindrical shell. The shell contains the governor by which the speed of the motor is maintained constant. The mode of regulation adopted by Mr. Brush consists in causing the governor to adjust the commutator automatically with relation to the brushes. To this end the commutator segments are mounted upon a sleeve on the shaft, so that they can be revolved to any desired extent under the influence of the governor.

The illustrations, Figs. 163 and 164, show the governor in detail. As will be seen, the commutator brushes $C C$ remain fixed, and loosely mounted on the shaft E is the commutator sleeve a , which turns freely. The commutator sections d are insulated from the sleeve a , and are connected to the armature bobbins by flexible wires, so as not to interfere with the rotary adjustment of the commutator. To the inner periphery of the cylindrical shell G , which is bolted to the shaft, the governor arms $H H$ are

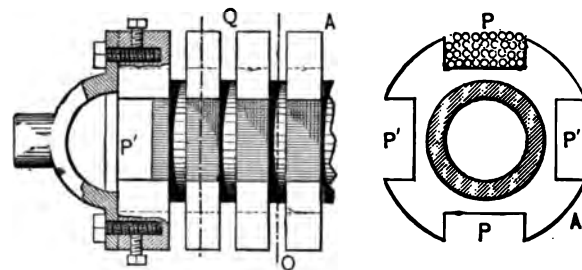


FIG. 161.—DETAILS OF BEATTIE ARMATURE.

pivoted. The inner free ends of the arms are connected to the opposite arms by means of spiral springs $I I$. In addition, the arms carry each an adjustable weight K . The links $L L$, attached to the arms $H H$, are connected to a disc upon the commutator sleeve. Hence, it will be readily understood that as the governor shell rotates with the pivoted weights $K K$, the latter, by centrifugal force, will be removed to-

ward the periphery of the shell, and, through the medium of the connecting links LL , will impart a rotary movement to the commutator, varying its position on the armature shaft.

The action of the governor is precisely analogous to that in a steam engine. When in a state of rest, the springs draw the weights toward each other and maintain the commutator segments at the maximum point of effect with relation to the brushes. When current is switched on to the motor, the governor weights in their revolution are thrown outward and ro-

points on the commutator nearer to the brushes, and thereby increase the speed of the motor. On the other hand, should the speed of the motor be increased above the normal rate, owing to an increase of current-strength or to a decrease of load, the governor balls will be caused to recede from each other and rotate the commutator in the same direction as that of the armature shaft, and cause the maximum points on the commutator sections to be moved away from the brushes, and thereby decrease the speed of the motor. In this manner provision

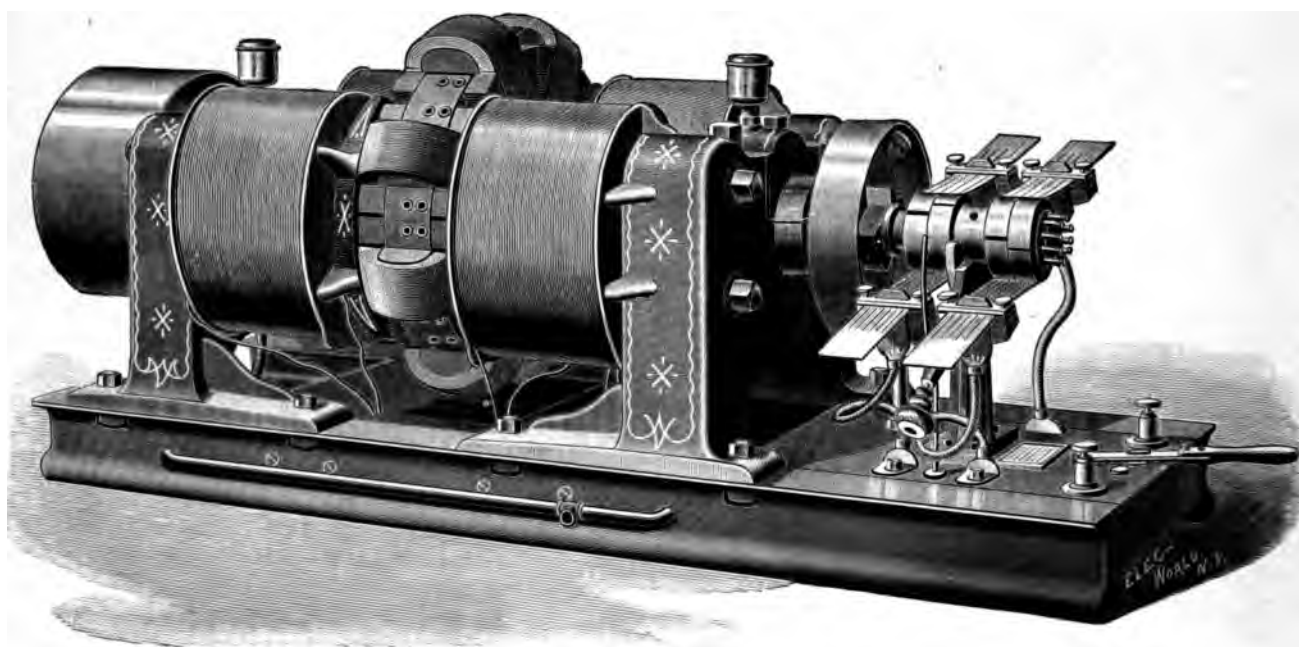


FIG. 162.—BRUSH MOTOR.

tate the commutator, carrying the maximum points away from the contact points of the brushes and in the direction of rotation of the armature. This action decreases the effect of the driving current until a point is reached where the effect of the driving current is balanced by the load on the motor, and the speed of the latter remains constant. Now, should the speed of the motor be retarded by a decrease of current-strength with no corresponding diminution of load, or by an increase of load with no increase of current-strength, the governor balls will be retracted and drawn toward each other by the spiral springs, and thereby rotate the commutator in a direction opposite to the motion of the armature shaft, the effect of which is to move the maximum

is made for all contingencies affecting the working of an electric motor. The parts constituting the governor are few and simple.

Another of the more recent systems designed for the purpose of running light machinery is exemplified in a neat combination of electric motor and battery, designed by, and named after, Messrs. Curtis and Crocker of New York.

The little motor, shown in Fig. 165, is series wound, having an internal resistance of .12 ohm, and is capable of carrying a current of 16 ampères with safety. At 2,000 revolutions it generates a counter electromotive force of six volts, with the current of sixteen ampères, and is said to exert a pull of five pounds on the circumference of the pulley, which is one and one-half inch in diameter. The magnet cores and

pole-pieces are continuous, and are wrought-iron drop-forgings. The armature of the motor is of a novel construction, on the Gramme principle, and is completely enclosed, so as to exclude all dust and keep it from accidental injury.

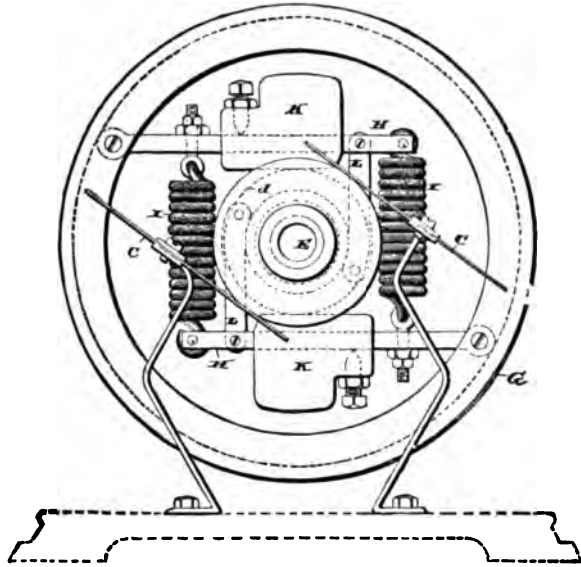


FIG. 163.—DETAILS OF GOVERNOR, BRUSH MOTOR.

In connection with the motor there is made a battery consisting of two cells, giving an electromotive force of nearly four volts, with a current of from eight and one-half to ten amperes. The chemicals used in the battery are made up in the form of bricks, which are dropped into

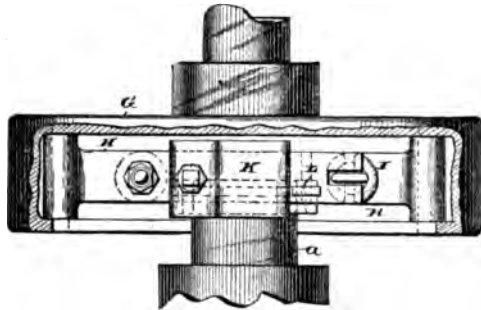


FIG. 164.—DETAILS OF GOVERNOR, BRUSH MOTOR.

the cells filled with water and soon bring the battery up to its full work. This makes the handling of the battery very convenient for those inexperienced.

Another feature is the method by which the speed of the motor can be regulated for fast and slow working. This is accomplished by sus-

pending the zincs of the battery upon a lever so that they can be immersed to any extent or raised entirely out of the solution. The lever is operated by hand, and falls into different notches. The strength of the current, depending upon the extent of the immersion of the zincs, can thus be regulated to any extent, and with it the speed of the motor.

Since the days of Pacinotti it has been known that dynamos and motors are reversible, and it is now known that it is almost impossible to put any assemblage of copper and iron together which, when a current is passed through it while in a magnetic field, will not show some evidence of motion. For some years past dynamo construction has been carried to a very high

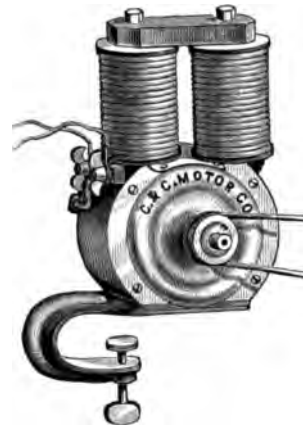


FIG. 165.—THE "C. & C." MOTOR.

degree of efficiency, and machines have been built which would convert ninety-six per cent. of the mechanical energy delivered to them into electricity. Yet, notwithstanding this fact and the assertion of Prof. Henry A. Rowland, that the best dynamo must be the best motor, in other words, that the best apparatus for converting mechanical power into electricity must be the best apparatus for converting electricity into mechanical power, a statement which on its face carries the elements of truth, electric motors have remained for a long time a subject concerning which most literature was sadly at fault, both the theory of the motor, a knowledge of its action, and its practical application being remarkably limited. One of the causes, perhaps, of the difficulty of handling this subject, has been that most motor experiments have generally been conducted with crudely made dynamo machines, and without any definite idea

of the relations that exist in the different parts of the circuit. The terms electromotive force, potential, current, and resistance, in their relation to what is commonly called the counter-electromotive force and to each other, have not been at all generally understood, nor even the law of the electro-magnet until Deprez and Hopkinson began their researches on the saturation of iron. Even to-day well-known scientific men differ on this latter law.

Deprez in Paris, Ayrton and Perry in London, and Sprague, among others, in the United States, have been the most active in developing the true theories of motors. Of the latter little was known in this line until the fall of 1884, when the Electrical Exhibition was held in Philadelphia. Mr. Frank J. Sprague had for some time before this been pushing his researches with energy, and at the Philadelphia Exhibition exhibited a number of machines which were the first of the kind ever shown. These machines were run on an Edison constant potential circuit. They were thrown into circuit gradually with a very strong rotary effort or torque, ran at constant speed with brushes at fixed points, and without any evidence of sparking, under all loads from the minimum up to the maximum allowed. In addition to those machines, Mr. Sprague showed others, one of which, starting under a heavy load, could be made to run forward or backward, fast or slow, at will, the reversal being made with an ease and rapidity and freedom from sparking which were remarkable. Another machine could be made to run in either direction, and was provided with adjustments so that it could be made to run at different determined constant speeds under varying loads. Since the exhibition of these machines, all of which were experimental and many of which are now in practical use, Mr. Sprague's progress in this work has been remarkably rapid. Some idea may be obtained of the operation of some of the different classes of machines built under the Sprague system from the following general explanations:

A motor when running may be looked upon as a dynamo machine propelled by a current; it has a field magnet like any other dynamo; it has an armature situated in that field which, either because of the attraction and repulsion of the lines of force, or of the double attraction and repulsion of the poles which are set up in

the armature acting on the poles of the field magnet, is caused to rotate. This armature rotating in the magnetic field has an electromotive force developed in it which is precisely of the same kind as would be developed were the motor driven by a belt instead of by a current. The strength of this electromotive force depends upon the resulting strength of field and the speed of the armature. This electromotive force, which may be termed a *motor* electromotive force, is ordinarily called the counter-electromotive force, because it is opposed to that of the line current which is flowing into the motor. The difference between this line electromotive force and that of the motor is what may be called the effective electromotive force, and determines, in combination with the resistance of the circuit, the strength of current which will flow in a circuit into which these elements enter. In any case of a single transmission from a dynamo to a motor the combination of these two determines the differences of potential which exist in the different parts of the circuit, which difference of potential determines the strength of current which will flow in any derived circuit. This counter-electromotive force likewise determines the efficiency of a motor or a system of transmission of power.

Motors may be described as belonging to one of three different systems. First, those in which the field magnet is excited by a coil in parallel circuit with the armature, that is, in shunt relation thereto; second, those in which the field magnet is in series with the armature circuit; and third, those in which there is a combination of these two circuits. There are in addition a very large variety of each of these classes, different conditions demanding different performance. Furthermore, similar machines may be placed upon three different kinds of circuits, their performances varying widely in each case. These three conditions are: First, the case of special transmission with varying potential and current; second, constant current circuits in which the main current is kept at a constant quantity, and third, constant potential circuits. The special transmission of power, unless carried out under certain well-defined laws based either upon a constancy of current or constancy of potential at some definite part of the circuit, is unsatisfactory, but if made according to a law no difficulties present themselves.

We will briefly consider the action of these different kinds of machines on two classes of circuits only. First, on the constant current circuit. If a series wound machine be placed upon such a circuit, the same current passing through the field magnet, it will develop a constant torque, which torque is directly proportional to the strength of the field magnet and to the current in the armature. If the mass of iron is sufficiently great this torque will be directly proportional to the effective ampere-turns in the field magnet, and the work done will be directly proportional to the speed. If the machine be at rest there will exist a difference of potential at the terminals of the machine equal to the product of the current and the resistance of the machine. When running, however, an electromotive force will be developed in the machine and the potential at the terminals of the machine will rise by the same increment. The work done may be likewise expressed by the product of this counter-electromotive force and the current, or eC , and is independent of the resistance of the machine. The resistance, however, determines, in combination with the other elements, the total efficiency of the motor. The total energy expended is the product of the difference of potential existing at the terminals of the motor and the current flowing, or EC . The effi-

ciency then is $\frac{eC}{EC}$, or $\frac{e}{E}$, and the heat wasted $(E - e)C$.

When running at any particular speed the work will be increased directly as the field magnet strength is increased. So also will be the economy. The heat wasted with any given resistance in a machine under these conditions is a constant. The direction of rotation of such a machine can be reversed by reversing either the armature circuit or the field circuit; if both circuits are reversed, then the machine will run in the same direction. For many classes of work this kind of machine is exceedingly useful, because it admits of a great range of hand control. If such a machine, however, be put on ordinary work, and this work be lightened up, the machine will run faster and faster, and unless the field is weakened or the brushes shifted to check it, the speed will practically increase without limit. Every change of speed and every change of

load is accompanied by a corresponding change in the potential which exists at the terminals of the machine. Moreover, on a constant current, the motors being in series with each other and with lamps, this continual variation of potential is apt to cause trouble on the circuit, especially if the machines are not automatic, since, as already stated, with any fixed field the torque is constant, the work done is directly proportional to the speed. The machine has the highest efficiency when running at the highest speed.

With shunt machines, however, the action on the constant current circuit is much different. Here the current is divided in two circuits, such division, when the motor is at rest, being inversely proportional to the resistances of the two parts of the circuit. With such a motor, the field is weakest when the machine is at rest, and its torque or rotary effort is also very weak. If the load be not too great, as the speed of the machine increases a counter-electromotive force is set up, the potential at the terminals of the armature and field magnets rises, the current in the armature diminishes, and that in the field magnet increases. Provided there is sufficient iron in the field magnets, the torque or rotary effort will vary in a decreasing ratio until one-half of the current is flowing through the field magnet. At this moment the machine will be doing its maximum amount of work, and at less than fifty per cent. total efficiency. If the work be lightened, the machine will increase its speed until, when the work is entirely removed, there will be practically no current through the armature; all will have been shunted through the field magnets, and the potential at the terminals of the machine will be at the maximum. Such a machine will do the same total work at two different speeds and efficiencies.

If a machine be wound with a double set of coils it will behave very much the same as a shunt machine does, its field magnet being strengthened in a more or less rapid ratio, or being kept constant, depending upon whether the series coil is cumulative or differential.

Because of the fact that constant current circuits in ordinary use deal with small currents and very high electromotive forces, and do not admit of such perfect regulation, Mr. Sprague has preferred ordinarily to work the constant potential circuits, although some of

his machines are running on the constant current circuits for other than automatic work; that is, for work where the speed is under control and where the work done for a given speed is constant.

There are two ways by means of which a constant current motor can be governed. One consists in automatically changing the counter-electromotive force by changing the position of the brushes on the commutator to positions more or less removed from their normal one. To this objection is offered because the proper position for the brushes of any machine is at the points of least sparking. The other method consists in varying the counter-electromotive force by automatically weakening the field as the load is diminished, or strengthening it as the load is increased. Several methods have been proposed for doing this, generally by the action of a centrifugal governor. To this also some objections are raised. Mr. Sprague, desiring to get rid of all such rapidly moving adjuncts to motors, is now engaged on a totally new system, which promises, he thinks, entire freedom from these defects.

On constant potential circuits the behavior of these different classes of motors is entirely different.

A plain series wound motor when there is sufficient iron in the field has a torque proportional to the square of the current flowing through it. It is capable of exerting a great rotary effort and doing a large amount of work at a slow speed. The range of speed for different loads is, however, great, and the motor is unfitted for ordinary work where steadiness of speed is an object; as the load is diminished, the speed increases and, if thrown off entirely, the motor will run faster and faster, the field continually growing weaker and the armature all the time accelerating its speed in a vain attempt to generate an electromotive force equal to the initial. For some classes of work, this kind of a machine, with some essential modifications, is exceedingly useful.

On the other hand, the shunt-wound machine will run fairly well on a constant potential circuit. The field, being excited independently of the armature, is constant, and since the load varies with the motor electromotive force, and the field is constant, it follows that the speed must vary with e . The torque is proportional to the current in the armature, and the

speed will be slowest with the greatest load and fastest with the lightest, that is, when $e = E$. The lower the resistance of the armature, the less the variation in speed.

It is with the third class of motors, when used on constant potential circuits, that the difficulties which are involved in the governing of a motor entirely disappear, and, without the use of any such apparatus as centrifugal governors or movable contacts, it becomes possible to satisfy the most exacting conditions, both as regards efficiency, steadiness of running, power to start under very heavy loads, and freedom from sparking.

When Mr. Sprague first proposed his constant speed machines for constant potential circuits, he enunciated the following seemingly paradoxical proposition:

In a motor with the armature and field magnet independently supplied, the work which the motor will do in a given time, its economy and efficiency, are all independent of the strength of the field magnet, provided the translating devices intermediate between the motor and whatever is the recipient of its energy are not limited as to the rate of transmission of the motor speed; and that in all cases where a motor is working on a constant potential circuit and not up to its maximum capacity, in order to increase the mechanical effect either of speed or power, or both, or to compensate for any falling off of the potential on a line, it is necessary to weaken the field magnets, instead of strengthening them, and *vice versa*.

The strength of the field determines the speed at which a motor must run to get a required efficiency. With a given initial potential at the armature terminals, no matter how the load varies from the maximum allowed, the speed may be maintained constant by changing the strength of the field; such strength being diminished as the load is increased, and, *vice versa*, increased as the load is diminished.

These facts may be demonstrated as follows:

Let us consider the motor current as derived from mains having a fixed difference of potential, and the motor with its field and armature in shunt relation. In this case the armature runs with a velocity dependent upon the strength of field, the initial potential, the number of turns, resistance, etc., of the armature, and the load, and a counter-electromotive force is set

up which regulates the armature current. The higher the speed the greater this counter-electromotive force. Let E be the initial and e the counter-electromotive force, and r the resistance of the armature. The current flowing in

the armature is then $\frac{E - e}{r}$. With a given arma-

ture and given field e varies with the speed. The power at any given speed and strength of field varies with the current, and with any given current varies with the strength of field. The total work done is the product of the speed by the work per turn, and since the speed is as e and the work per turn as the current

$\left(\frac{E - e}{r}\right)$, the total work done is expressed by $\frac{e(E - e)}{r}$. The efficiency is the ratio $\frac{e}{E}$. It will

be seen that both these expressions—the total work done and the efficiency—are independent of any function of the field, but depend only on the initial and counter-electromotive forces and the resistance of the armature, and any given value of e can be attained with any strength of field by attaining proper speed.

Considering the speed of machine constant, its field alone being varied, and differentiating

the expression for work done, $\frac{e(E - e)}{r}$, we have $\frac{de}{r} \left(E - 2e \right)$ as the rate of variation of work.

It follows then that to maintain the speed constant with a current of constant potential under varying loads, when the load increases so that the speed would naturally decline, the field is weakened, the counter-electromotive force diminished and armature current increased, the tendency to reduced speed is counteracted, and there is an increase in the mechanical effect—power. For a decreased load the field is strengthened, the counter-electromotive force increases, the current decreases, the speed remains the same, and the power is decreased.

To maintain speed or power constant under varying initial potential, if the potential at the motor terminals increases, these mechanical effects increase or tend to increase. By strengthening the field an increased counter-electromotive force is produced, so that the increased

power or speed, or the tendency thereto, is counteracted, and this counteraction may evidently be itself considered a decrease in mechanical effect, whether the regulation is performed simultaneously with the increase of potential or before or after such increase. If the regulation is performed simultaneously, with a gradual change of potential, there may be less change in counter-electromotive force or armature current; but there is still the counteracting of the tendency to increased mechanical effect, which counteracting is itself a decrease of mechanical effect. For a decreased or decreasing initial potential, the field is weakened to counteract the decrease in mechanical effect which would otherwise occur, and therefore to produce an increased mechanical effect.

Hence to change the speed or power of a motor on a circuit of constant potential, the speed or power is increased by weakening the field, which produces a decreased counter-electromotive force and an increased armature current, and consequently the increased mechanical effect desired; and such mechanical effect is decreased by strengthening the field, and thus increasing the counter-electromotive force.

In brief, then, Mr. Sprague's method of regulation consists in strengthening the magnetizing effect of the field-magnet coils of the motor to decrease the mechanical effects, such as speed or power, or both, and *vice versa*, weakening such magnetizing effect to increase the mechanical effects, and under varying loads the speed is maintained constant by an inverse varying of the strength of the field magnets.

This may be accomplished in two ways, one by varying the field circuits by a mechanical governor which responds to any variation in the speed of the motor. This, however, is not satisfactory, and Mr. Sprague's ordinary method of working is to make use of certain coils in series with the armature and dependent upon it, which coils have a resultant magnet action which is opposed to that of the main coils of the machine. While the main principle is the same, Mr. Sprague has a number of different methods of applying it. The first has a series coil in series with the armature, and its action in the above laws will be understood from the following description. All these machines, it should be said, could be used as constant speed machines on constant current circuits, provided the field coils are properly proportioned for the

current which they would have to carry, but with certain disadvantages, as will be shown.

The magnetic moment of a coil may be defined as the product of the ampères flowing therein by the number of turns, and if the main and governing coils are practically similarly situated with regard to the field-magnet cores, the magnetic field may be considered as proportional to the effective magnetic moment; that is, to the difference of the magnetic moments of the shunt and series field coils, so long as we are working on a straight or nearly straight line characteristic. This characteristic can be determined for any particular cores in any of the well known ways; for instance, by running the motor as a dynamo at a constant speed, passing variable known currents through the field coils, and noting the potential existing at the free armature terminals.

For a properly constructed motor the field magnet must at no time be too highly saturated, that is, it must be worked with a characteristic which is a straight or very nearly a straight line.

Let f denote the resistance of the main or shunt field coils; m the number of turns therein; r the resistance of the differential or series field coils, and n the number of turns; E , the difference of potential at the shunt terminals; e the counter-electromotive force set up in the armature; and R the resistance of the armature.

The work done $= e \frac{E - e}{r}$; that is, it depends

upon e , a variable quantity, and upon the constants E and r .

Now e varies with the speed and field, or the effective magnetic moment of the field, but the conditions are that the speed remains constant, hence e must vary with the field alone.

$$\text{Current in shunt field} = \frac{E}{f};$$

$$\text{Magnetic moment of same} = m \frac{E}{f};$$

$$\text{Current in series field} = \frac{E - e}{R + r};$$

$$\text{Magnetic moment of same} = n \frac{E - e}{R + r}.$$

The effective magnetic moment must then be

$$m \frac{E}{f} - n \frac{E - e}{R + r};$$

and the conditions are such that (for two different counter-electromotive forces or two different loads)

$$\frac{e}{e^1} = \frac{m \frac{E}{f} - n \frac{E - e}{R + r}}{m \frac{E}{f} - n \frac{E - e^1}{R + r}};$$

$$\text{or, } \frac{e}{e^1} = \frac{m E (R + r) - n f (E - e)}{m E (R + r) - n f (E - e^1)};$$

$$\text{or, } \frac{e}{e^1} = \frac{m E (R + r) - n f E + n e f}{m E (R + r) - n f E + n e^1 f};$$

$$\text{or, } e m E (R + r) - e n f E + e n e^1 f = e^1 m E (R + r) - e^1 n f E + e^1 n e f.$$

Cancelling we have $e m (R + r) - e n f = e^1 m (R + r) - e^1 n f$,

$$\text{or, } m (R + r) (e - e^1) = n f (e - e^1),$$

$$\text{or, } \frac{m}{n} = \frac{f}{R + r}.$$

That is to say, the number of turns in the shunt coil must bear the same ratio to the number in the series coil as the resistance of the shunt coil bears to the sum of the resistance of the series coil and the armature.

This is the Sprague law of winding for a machine of the kind mentioned, and so wound it will be self-regulating for any constant potential up to the maximum allowed by the construction of the machine, and from no load up to the maximum.

There is a feature of motors so wound which may be here noticed.

The ratio of the magnetic moments of the shunt and series fields is

$$\frac{m \frac{E}{f}}{n \frac{E - e}{R + r}} \text{ or, } \frac{m E (R + r)}{n f (E - e)}.$$

$$\text{But } \frac{R + r}{f} = \frac{n}{m}.$$

$$\text{Hence the above ratio} = \frac{m E n}{m n (E - e)} \text{ or, } \frac{E}{E - e}.$$

That is, the ratio of the initial to the effective electromotive force is the same as the ratio of the moments of the shunt and series coil.

$$\text{When } e = 0 \text{ this ratio becomes } \frac{E}{E} = 1; \text{ that}$$

is, the moments are equal, and this means that, in a perfect machine, if both coils be closed and in their normal position, for any potential or current, a zero field, or practically so, will be formed, and the motor will either not start at all, or, if it does start, will run at a very great speed, take the maximum current at any given potential, and do little or no work at all.

How to obviate the bad effects of this peculiarity, yet to take advantage of it, will be shown later.

What has already been pointed out may be again stated, that the motor will regulate itself perfectly for all potentials so long as we work with a straight line characteristic, but it must be with a theoretical efficiency of not less than fifty per cent., for if we go below this, the governing coil works in the wrong direction.

$$\text{Referring to the equation } \frac{m}{n} = \frac{f}{R + r}, \text{ it will}$$

be seen that m and n can be increased in the same ratio. That is, if means are provided for varying the effective magnetic moments of shunt and series coils the motor can be set to run at different determined speeds. It is evident that f and r can also be varied to change the speed.

Let us now consider the same class of motors with constant speed, varying load, and *constant current*.

Let the resistances and turns be designated as before. Let K be the constant current. Let E be the variable potential at the terminals of the motor and e the variable counter-electromotive force.

$$\text{The work done} = \frac{e(E - e)}{R + r}.$$

We must eliminate E , making it dependent upon e and the constants R , r , f , and K , and hence the work can be expressed in terms of R , r , f , K , and e , of which e is the only varia-

ble quantity; e depends upon speed and field, but speed is constant. Hence our conditions require that with the same current we make e , and hence the work, variable, but by changes in the field alone.

$$\text{Field current} = \frac{E}{f};$$

$$\text{Armature current} = \frac{E - e}{R + r}.$$

$$\text{But } K = \frac{E}{f} + \frac{E - e}{R + r};$$

$$\text{or, } f(R + r)K = E(R + r) + fE - fe;$$

$$\text{or, } f(R + r)K + fe = E(R + r) + fE;$$

$$\text{or, } \frac{E}{f} = \frac{(R + r)K + e}{R + r + f}, \text{ and } K = \frac{E}{f} = \frac{fK - e}{(R + r)K + e}.$$

$$\text{Moment of shunt field} = m \frac{(R + r)K + e}{R + r + f}$$

$$\text{Moment of series field} = n \frac{fK - e}{R + r + f}.$$

$$\text{Effective moment} = \frac{m(R + r)K + me - n(fK - e)}{R + r + f}.$$

Our conditions are such that

$$\frac{e}{e^1} = \frac{m(R + r)K + me - n(fK - e)}{m(R + r)K + me^1 - n(fK - e^1)};$$

$$\text{or, } e m(R + r)K + mee^1 - n f K e + n e e^1 = e^1 m(R + r)K + m e e^1 - n f K e^1 + n e e^1.$$

$$\text{Cancelling and transferring, } m(R + r)(e - e^1) = n f (e - e^1);$$

$$\text{or, } \frac{m}{n} = \frac{f}{R + r},$$

which is the same law as found for constant potential.

$$\text{The ratio of moments is } \frac{m(R + r)K + me}{n f K - n e}.$$

$$\text{When } e = 0 \text{ this becomes } \frac{m(R + r)}{n f}.$$

$$\text{But } \frac{R + r}{f} = \frac{n}{m};$$

$$\text{hence substituting we have } \frac{m n}{n m} = 1.$$

That is, if the motor is at rest and any current is sent through it a zero field will be produced. This of course follows from what has been already said about the constant potential motor.

The potential E which will exist if $e = E$ and no current is passing in the armature is fK , and the maximum work is done when $e = \frac{fK}{2}$.

To be self-regulating, the motor can be worked up to this point, but not beyond it, for then the regulating coil works in the wrong direction.

In another variety of motor this series coil is placed outside the terminals of the shunt coil. The laws governing the action of this machine on a constant potential circuit may be described as follows:

Let the same letters of reference be used.

Then the potential existing at the shunt terminals will be $E = rC$.

$$\frac{E - rC}{f} = \text{shunt current};$$

$$\frac{E - rC - e}{R} = \text{armature current};$$

$$\frac{E - rC}{f} + \frac{E - rC - e}{R} = C;$$

$$ER - rCR + fE - rfC - ef = CRf;$$

or, $CRf + rfC + rRC = fE - ef + ER.$

$$\text{Whence } C = \frac{f(E - e) + ER}{fR + (f + R)r}.$$

$$\text{Work done} = e \frac{E - rC - e}{R}.$$

But since C can be expressed in terms of e and constants, the work can be also expressed in terms of e and constants.

$$m \frac{E - rC}{f} = \text{shunt current},$$

$$n C = \text{series current};$$

$$m \frac{E - rC}{f} - n C = \text{effective current},$$

$$= m \frac{E - r \frac{f(E - e) + ER}{fR + (f + R)r}}{f} - n \frac{f(E - e) + ER}{fR + (f + R)r}.$$

But our conditions are such that

$$\frac{E - r \frac{f(E - e) + ER}{fR + (f + R)r}}{m} - n \frac{f(E - e) + ER}{fR + (f + R)r},$$

$$\frac{E - r \frac{f(E - e^1) + ER}{fR + (f + R)r}}{m} - n \frac{f(E - e^1) + ER}{fR + (f + R)r}$$

$$\frac{e}{e^1} = \frac{mE[fR + (f + R)r] - mr[f(E - e) + ER]}{mE[fR + (f + R)r] - mr[f(E - e^1) + ER]};$$

$$\text{or, } mEefR + mEefr + mEerR - merrfE + merrfe^1 - merrER - enf^2E + enf^2e^1 - enfER = mEe^1fR + mEe^1fr + mEe^1rR - me^1rfE + me^1rfe - me^1rER - e^1nf^2E + e^1nf^2e - e^1nfER.$$

Cancelling we have—

$$mfR(e - e^1) = nf^2(e - e^1) + nRf(e - e^1);$$

$$\text{or, } \frac{m}{n} = \frac{f + R}{R}.$$

That is, the number of turns in the shunt main field bears the same ratio to the number of turns in the series differential field, as the sum of the resistances of the shunt field and the armature bears to the resistance of the armature.

This is the Sprague law of winding for a machine of this character, and so wound the machine will be self-regulating for any constant potential and for any load up to the maximum allowed, and even with a resistance in circuit and with varying potential.

The same peculiarity exists in those motors which has been pointed out in connection with the first class of differentially wound motors, and this will now be described.

The ratio of the magnetic moments of the shunt and series fields is.

$$\frac{m E - m r \frac{f(E-e) + ER}{fR + (f+R)r}}{f};$$

$$\frac{nf(E-e) + nER}{fR + (f+R)r};$$

$$\text{or, } \frac{mE[fR + (f+R)r] - m r [f(E-e) + ER]}{f[nf(E-e) + nER]}.$$

If $e = 0$, this becomes

$$\frac{mE f R + mE f r + mERr - m r f E - m r ER}{f^2 n E + f n ER};$$

$$\text{or, } \frac{mR}{n(f+R)}.$$

$$\text{But } \frac{m}{n} = \frac{f+R}{R}.$$

$$\text{Hence the ratio becomes } \frac{m}{n} = \frac{f+R}{R} = 1.$$

That is to say, if a motor of this character is at rest and the series coil in its normal governing position, and the circuit be closed to the motor, a zero field, or nearly so, will be produced; for under these circumstances the magnetic moments are equal, and either the motor will not start at all, or, if it does start, will run at a very great speed, take the maximum current at any given potential, and do little work or none at all.

Referring to the equation $\frac{m}{n} = \frac{f+R}{R}$ it will

be seen that m and $f+R$ can be increased in the same ratio. This means that the determined constant speed of the motor can be varied for any given potential. Also m and n can be increased in the same ratio—that is, if means are provided for varying the effective magnetic moments of shunt and series coils, the motor can be set to run at different determined speeds.

This motor with constant speed, varying load, and *constant current* will now be considered.

Let the turns, resistance, etc., be designated as before. E is the variable potential at the terminals of the shunt field, and e the corresponding counter-electromotive force.

We must eliminate E and express the work in terms of e and constants; e depends on speed and strength of field, but since speed is constant e depends on the field alone.

$$\frac{E}{f} = \text{current in shunt field,}$$

$$\frac{E-e}{R} = \text{current in armature,}$$

$K = \text{current in series field;}$

$$\text{and therefore } K = \frac{E}{f} + \frac{E-e}{R};$$

whence $fR K = ER + (E-e)f$:

$$\text{or, } \frac{E}{f} = \frac{RK + e}{f+R}.$$

$$\text{The conditions are } \frac{e}{e^1} = \frac{\frac{mRK + me}{f+R} - nK}{\frac{mRK + me^1}{f+R} - nK};$$

$$\text{or, } \frac{e}{e^1} = \frac{mRK + me - fnK - RnK}{mRK + me^1 - fnK - RnK};$$

$$\text{or, } emRK + me e^1 - fnK e - RnK e = e^1 mRK + me^1 e^1 - fnK e^1 - RnK e^1;$$

$$\text{or, } (e - e^1) mRK = (e - e^1) fnK + (e - e^1) RnK;$$

$$\text{or, } \frac{m}{n} = \frac{f+R}{R}.$$

This is the same law of winding that holds when a machine of the same class is used for constant potential; and the same remarks in regard to the zero field apply as in the former case.

Also, as in the former case, the speed for any given current can be varied by varying the resistance and turns or the effective turns.

From the foregoing demonstrations, it follows that a motor of either class depending for its regulation on this differential winding will regulate with a constant current only when working at less than fifty per cent. armature efficiency; and that the same machine with the same winding will regulate on a constant po-

tential circuit only when working at over fifty per cent. armature efficiency.

The laws above set forth are for pure electro-dynamic motors; if there is any permanent magnetism, as in hard cast iron, or where permanent steel magnets are used, the law of winding is modified in so far as the residual or permanent magnetism is the equivalent of an electro-magnetic moment; but in this case, too, there should exist a zero field if the governing coil is normally closed when the motor is at rest.

The fact already pointed out, that in the best self-regulating motor there is a zero or very weak field when the motor is started, necessitates in both classes of motors, especially when it is desired to start at a speed not greater than the normal, or when there is any load on the motor, in which case there is danger of burning out, the use of devices whereby the action of the governing coil may be modified.

This may be done by the introduction of a resistance, by shunting the coil with a resistance or by the variable shunting of the armature upon the main field. Mr. Sprague, however, prefers to use a switch to short-circuit the governing coil or to short-circuit and reverse it. If it is reversed, then the first rush of current makes a very strong field instead of reducing it to zero or nearly so, increases the rotary effort and prevents the burning out of the machine.

As an instance, if a constant potential motor has the series coil reversed when the full circuit is closed, if there is margin enough on the field characteristic we shall have a field twice as strong as the strongest normal field, four times the strength when the motor is doing its maximum work per unit of time, and a momentary rotary effort eight times that existing when the maximum work is on. As soon as the speed comes up, the governing coil is short circuited and then reversed, and then the motor is self-regulating.

Having obtained a machine which was thus automatic, Mr. Sprague made another step in overcoming the distortion or, rather, counteracting the distortion set up by the armature, by producing a distortion in the field magnets, which is dependent on precisely the same current that flowed through the armature, and he uses two methods, of which one only will be described.

Main field-magnet coils are employed in shunt relation to the armature, differential field-magnet coils in series with the armature, and additional accumulative field-magnet coils, also in series with the armature. The main field coils may be shunted upon the armature alone, or upon the armature and both the cumulative and differential series coils, or upon the armature and either of the series coils, the other series coil remaining outside the terminal of the main field shunt.

The object sought is to maintain the non-sparking points of the commutator cylinder constant by opposing the distortion of the magnetic field due to variations in the armature current by a counter distortion dependent upon such variations, whereby the magnetic resultant due to the armature and field magnet is unchanged, and the line of parallel cutting of the lines of force or point of least sparking is maintained in the same position.

In accomplishing the counter distortion of the field, the motor used is one in which the field-magnet cores extend in different directions from the field of force in which the armature revolves. The differential series coils are wound or arranged so that their greatest effect is produced on diagonally opposite parts of the magnetic field; and the cumulative series coils, so that their greatest effect is produced on the other diagonally opposite parts. The differential coils are arranged to have a greater magnetizing effect than the cumulative coils. A decrease of load, causing a decreased armature-current, tends to shift the magnetic resultant of the armature and field magnet; but this also decreases the magnetizing effect of all the series coils, and therefore the parts of the field principally affected by the cumulative coils are weakened, and those principally affected by the differential coils are strengthened, whereby a distortion of field is produced opposed to that produced by the decrease of armature current, and hence the magnetic resultant—the line of parallel cutting and the points of least sparking—remains unchanged. Thus no shifting of the commutator brushes is ever required, except on account of wear.

The arrangement of two sets of series field coils—one differential, the other cumulative—may be employed simply as a means of field regulation where it is not desired to produce

the counter distortion. In such case the coils may be evenly wound on all the legs of the field magnet and used only to regulate the motor, being wound in the proportions above stated. The differential and cumulative series coils have a differential effect, which, as the differential coils predominate over the cumulative coils, produces a weakening of the total strength of the field magnet when the armature current increases, and a strengthening of the field magnet when the armature current decreases, and so maintains constant the speed of the motor.

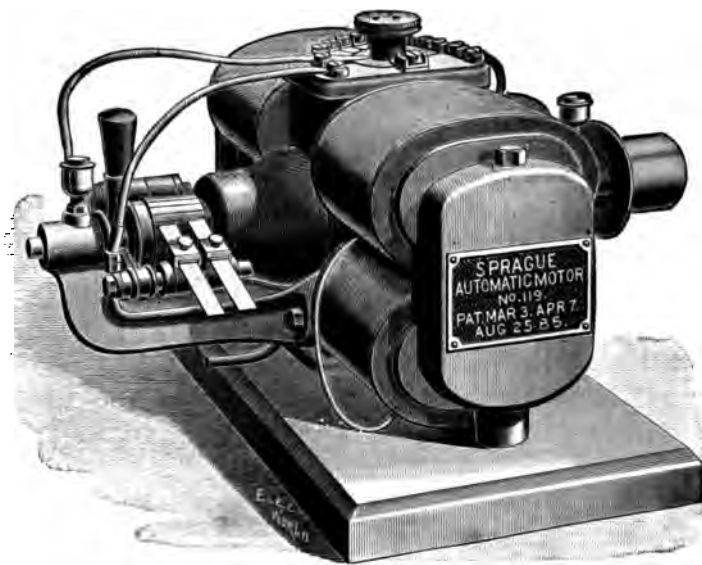


FIG. 166.—SPRAGUE ELECTRIC MOTOR.

One of Mr. Sprague's methods for varying the speed and power is to wind the field magnets with a series of coils of different cross section and resistance. These coils are all in series with each other, and the bights of the coils are brought to a commutator.

In the simplest form of this motor, one end of the armature circuit is connected with a contact arm arranged to travel over a contact range, thereby making electrical connection with different sections of the field coils. The other end of the armature circuit is connected with one end of the series of field coils, preferably at the junction of such series with the supplying circuit. As the arm moves over the successive contacts the armature is shunted around a greater or less number of the sections of the field coils, and the difference of potential between the terminals of the armature cir-

cuit is varied between the maximum and zero; but in this arrangement it is not reversed unless the connections are reversed. The contact arm is provided with an adjustable contact piece, to allow for wear. In another method, where a single set of field coils is broken up into sections, the wires from the bights are connected in a special manner to a circular range of contact pieces, and a double arm, the two parts insulated from each other and bearing on opposite sections, is used. To each of the arms is connected an end of the armature circuit, and as the arms are made to travel around the con-

tact range the difference of potentials at the arms or the brush terminals is reduced from the maximum to zero, is then reversed, and increases; and if the arms continue in the same direction another half revolution it is diminished to zero, changed again, and increased to the original maximum. The connections of the field sections are made thus: the first and last to single and opposite blocks of the range; the next adjacent sections have double connections to the next adjacent blocks on either side of the first ones connected; the next sections to the next adjacent pairs of blocks on either side, and so on till the blocks meet. In a third method two series of field-coil sections are used, and the bights connected to two ranges of contact pieces arranged in one or two circular or partly circular sets. Here, also,

two arms insulated from each other are used, and the two arms are connected to the two terminals of the armature circuit—that is, the armature circuit becomes what corresponds to the galvanometer circuit in the Wheatstone bridge. As the arms are made to travel over the successive contact surfaces, the difference of potential existing at these arms or at the terminals of the armature circuit decreases from the maximum to zero, changes, and increases again to the maximum reverse potential.

In this last arrangement the speed, torque, and direction of rotation can be varied as rapidly as desired without any sparking at the moment of reversal.

In types 1 and 3 as referred to above and illustrated in Fig. 166, the standard machines are wound in the sectional method described and in addition are arranged so that when the

motor is started the governing coil is in series with the armature and works accumulatively, while the potential at the armature terminals is progressively raised by moving along the field sections by means of the commutator at the top, part of the field sections being in series and the rest in shunt with the armature; this arrangement gives a very strong rotary torque; when full potential has been reached, the coarse coils are short circuited and then re-

up to the maximum, and promptly recover their normal speed under sudden and marked changes in load. There is no change necessary in the lead of the commutator brushes.

In the larger type of machines, however, two forms of which are shown in Figs. 167, 168, and 169, Mr. Sprague prefers to use a rheostat for throwing the machines into circuit, instead of winding the field coils in sections, because it is a much cheaper process of working, and as

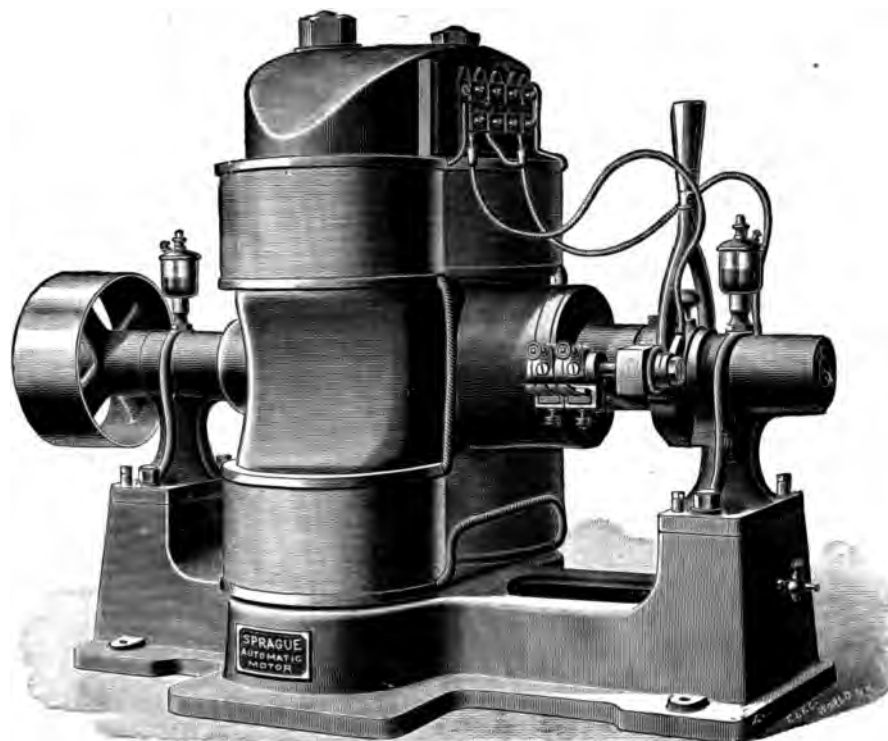


FIG. 167.—SPRAGUE ELECTRIC MOTOR.

versed and the machine becomes an automatic machine, having the following qualities:

It can be thrown into a circuit at a dead rest or slow speed, without any disturbance of potential and consequent flickering of light. It can be started gradually, whether free or under full load, without burning of brushes or flickering of light, the potential at the brushes being raised progressively from zero to maximum. If the load is such as to prevent starting until the full difference of potential exists at the brushes, the motor then starts with a rotary effort, or torque, very much in excess of what exists under the condition of maximum work. These motors are perfectly automatic, running at nearly the same speed for all loads

in case a heavy machine should be damaged in the sectional winding, it would be far more costly to make repairs to it than in the case where a rheostat is used. Of course this rheostat carries no current, except at the moment of starting the motor. These motors will lower a varying weight at the same speed that they will pick it up, and with the same freedom from sparking.

In another form, a variable speed machine, such as is now in use in the Western Union operating room, the rheostat is of peculiar construction. By a single movement of the switch the machine is thrown into circuit with a very strong field, the potential at the armature terminals is gradually raised, and after full potential

has been reached a resistance is then thrown into the field magnet, and the field thus weakened so that the speed of the machine is increased. This method of working allows of the finest gradations of speed.

Another machine which is just being brought out for use on constant potential circuits permits of nine or ten variations of speed from a single switch movement without the use of any external rheostat, and another type permits of a like variation of speed and entire reversal of movement, also with the single switch. This latter type is designed for operation on street cars.

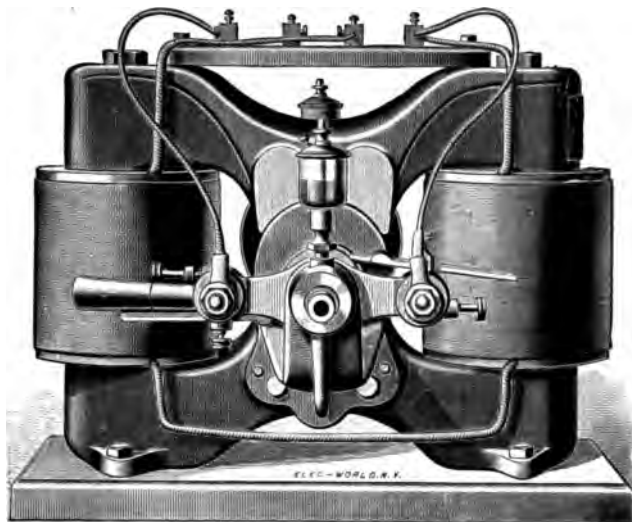


FIG. 168.—SPRAGUE ELECTRIC MOTOR.

For all ordinary work motors are built for constant potential circuits of about 100 volts. But the demand has come for 220 volt machines to go on the Edison three-wire circuits. Before long the Sprague Company expect to undertake some special cases of transmission of power in connection with mining work which involve the transmission of very large powers over long distances and under high pressure, such as 200 horse power sixteen miles with 1,000 volts at the motors, the entire electrical conditions being perfectly automatic, both at the generating and receiving end. A very large number of special problems are now being considered and motors are about to be used where none but the most enthusiastic believers in their adaptability will believe it possible.

Among the very interesting facts which have been brought out by experience is this, that on all ordinary classes of work motors do not

average over thirty-five to forty per cent. of the maximum capacity which may be safely demanded of them. A central station hence can take advantage of this falling off of work, and since there is an actual recovery of about sixty-five per cent., and this sixty-five per cent. is only about forty per cent. of the capacity of the motors which are in operation, it follows that, for every 100 horse power in a steam engine at a central station, including ten per cent. loss on distribution where the work is widely distributed, about 170 horse power can actually be contracted for.

We come next to Mr. Sprague's work in connection with electric railways. In December of 1885, a paper was read before the Society of Arts, Boston, by Mr. Sprague, on the subject of the application of electricity to the propulsion of motors on the elevated railroads of New York. This paper was an elaborate technical article which made a thorough investigation of the power used and its distribution, and indicated some of the methods which the writer proposed to carry out in the system that he had devised. The Third Avenue Elevated Road was taken as an example. It was shown that on this road the work was expended in three different ways, viz.:

1. In overcoming the inertia of the train, which was fifty-nine per cent. of the total.
2. In lifting the train on up grades, which amounted to twenty-four per cent.
3. In traction, seventeen per cent.

It was pointed out that because of the great frequency of stoppages and the necessity of high speeds on this road, most of the energy of the train which was put into it on getting under way and lifting it on up grades was of little value for traction. At the time the paper was written, there were at commission hours sixty-three trains in operation at one time on the up and down tracks. This was on a double track line of only eight and one-half miles length. The aggregate power that the engines on this road were capable of exerting was nearly 11,700 horses, the engines being of about 185 horse-power capacity. The average power exerted during the time trains were in motion was 4,640 horses, or, for the entire time on a trip, including stoppages, about seventy-four horses for each train of four cars.

The problem of how to handle this tremendous power on grades running up as high as

105 feet to the mile, with trains stopping every third of a mile, and sometimes not half a station apart, and sometimes reaching a speed of twenty to twenty-two miles an hour, is no mean one. It is true that small roads have been operated, among them one six miles long at Portrush, Ireland, but the conditions are totally different, and the demands which would be made upon an electrical system by the conditions of service on the elevated railroads present a new problem, and this problem not alone an electrical but also a mechanical one.

The great amount of power which is used on the elevated railroads and the distance over which the trains are hauled necessitate in the electric circuit large currents of a high potential. The potential decided on was 600 volts, and the experiments on the Thirty-fourth street section have been carried on with that pressure. No such electrical potential has ever been used in practice for this kind of work. The occasion for it has not existed, and motors which might be used with small powers over short distances and with low potentials would not avail there.

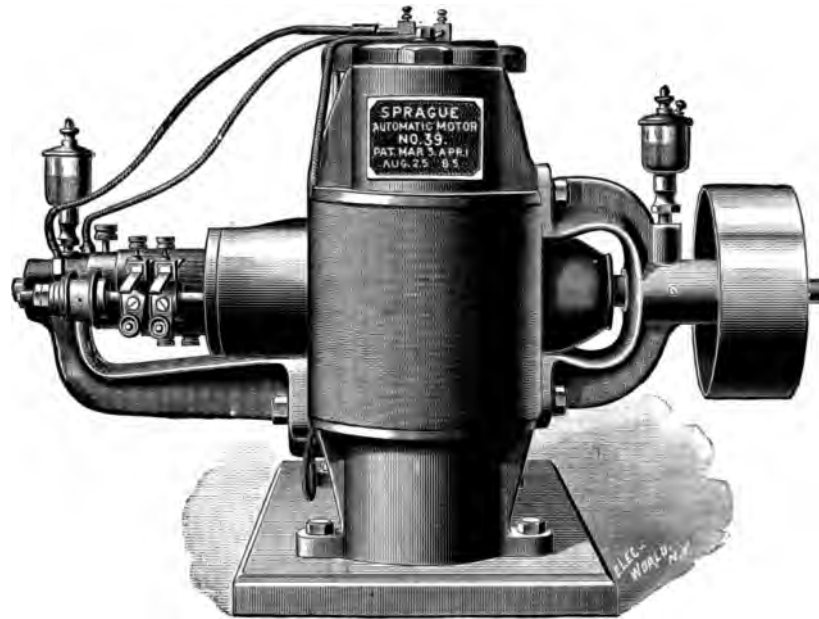


FIG. 169.—SPRAGUE ELECTRIC MOTOR.

The elevated system presents the result of a great many years of careful thought in engineering study. It is the culmination of a great many improvements. It has been carried to a degree of efficiency far higher than its most earnest supporter thought possible. It has been taxed to its uttermost. Recognizing these difficulties, Mr. Sprague has been for a long time engaged in the elaboration of a system which for some months past has been in experimental operation on the north track of the Thirty-fourth street branch of the Manhattan Railroad. Car No. 293, a full-sized standard passenger car of the elevated railroad, was placed at his disposal by the officers of the Manhattan Company, and this has been equipped and is now a thorough-going experimental car in which a great many problems are being worked out.

Some idea of the current and potential necessary for operating the Third avenue line may be easily gathered from the following facts.

As mentioned above, there are at one time 4,640 horse power actually being developed. With an efficiency of eighty per cent. for the motors, this would mean a current of 43,291 ampères if one hundred volts were maintained at the terminals of the motors. With 600 volts this would be reduced to 7,215 ampères. The handling of a current of 7,215 ampères and of from 600 to 665 volts electromotive force is a somewhat difficult matter. A conductor to carry this amount of energy without a very large loss under ordinary conditions must be large, but with the stations properly put in and with the rails properly reinforced, together with the methods of working which will be described more in particular below, it will be

seen that the difficulty of handling this has been very largely reduced. We will now enter into a somewhat detailed description of this system, both with regard to what is being done and what will probably be done in the future.

The first subject to be considered is the generating station. The system preferred by Mr. Sprague is the operation of a number of dynamos wound so as to generate at their normal speed and with a full load an electromotive force of about 670 volts at their terminals. These dynamos are wound for constant potential circuits. They are of very low armature resistance, and have high-resistance shunt fields. The dynamos may be built so as to maintain a constant potential under all loads at the junction of the mains with the track. There is one disadvantage, however, about this, and that is, if the electromotive force of the dynamos rises automatically, and there should be any very serious cross on the line, the machines might be burned out. Where they are wound with the field magnets in a simple shunt circuit, and no cumulative coil in series with the armature, any very bad cross on a line will lower the potential at the terminals of the machines, and while a very heavy load will come upon them for a brief interval of time, the drop of potential at the terminals will be sufficient to so far demagnetize the field magnets that the machines cannot be burnt out. In addition, however, to the ordinary shunt coil, Mr. Sprague employs a special winding, one which now appears in his railroad motors. This special winding is a coil in series with the armature, whose polarity is exactly at right angles to the polarity set up by the shunt coils, and is so proportioned that it automatically maintains the point of non-sparking coincident with the line of contact with the brushes on the commutators. This series coil would not have the effect of an ordinary cumulative coil. It would not raise the potential of the dynamos, but simply makes them non-sparking with fixed brushes under all loads.

Considering the length of road and the amount of power used it would be better to have two central stations instead of one. These stations would be of the most improved possible mechanical construction. The engines would be compound, condensing, and placed near the water. By this means the coal con-

sumption could be reduced at the central station to as low as two pounds of coal per indicated horse power. By having two stations, each removed about a quarter of the distance of the length of the road from either end, the size of conductor which is necessary for the middle rail is only one-fourth that which would be required were there only one station in the middle. Furthermore, the points of supply of current from each station should be maintained at the same differences of potential, to obtain which Mr. Sprague runs an independent line wire from station to station, with suitable indicators in it, showing whenever there is any inequality of potential existing at the supply points. This is done because the highest possible economy requires perfectly equal differences of potential at all points of supply, no matter how many the trains, nor where they may be situated on the track. The combined capacity of the two stations would be something more than equal to the highest total horse power appearing at any one time on the road, which, as we have seen, is about 4,700 horse power. It will be noted that there are no losses allowed for here. Why this is so will be explained in describing the system of braking which is used. This, then, would give a capacity at each station of about 2,500 horse power. On account of the rise and fall of the work done on the line, it being light at night, somewhat heavier during the middle of the day, and at its maximum during the morning and evening, this 2,500 horse power would be divided up into about four units, and to allow for any break-down of an engine these units would be of about 800 horse power each. The travel on the road is so perfectly known, and follows such a well-defined law of increase and decrease, that there would be no difficulty whatsoever in starting the engines at the proper time and throwing the dynamos into circuit. This system of power generation would be the most economical possible. With improved boilers and improved methods of burning cheap fuels, and with high grades of engines, compounding and condensing, results would be obtained which would be very gratifying.

We come now to the system of distribution, and this will be described more particularly with regard to the demands of the elevated railroads, leaving out particular reference to street roads, which form a department by them-

selves. There are many things which pertain to this system of distribution which would, of course, appertain to street work. The main rails are grounded, and form one side of the circuit, being connected to the structure of the road at suitable intervals. Four single rails, together with the superstructure and the ground connections, form a path of very low resistance, and there would probably be no need of any reinforcement at the fish-plates. Should such reinforcement be found to be advisable, a short connecting piece would be made from one rail to another, very much in the same manner as is now done where the track is used for electric signals, or, as with the middle rail, a main conductor would be used. The other part of the circuit consists of a very light rail of special construction, thoroughly well insulated in a simple manner, and raised so that its top is from three to four inches above the plane of the ordinary traffic rails. This rail is not continuous, being of necessity broken at all switches, turn-outs, sidings, and cross-overs. The ends terminate about eighteen inches from all crossing traffic rails, and instead of ending abruptly, they are bent down slightly, so that when the collecting wheels, running on the central rail, leave or enter them, they do so without any shock or jar to the spring mechanism which carries them. This middle rail is further divided up into sections of any convenient length desired, say at intervals of 500 or 600 feet.

In addition to this middle rail, there extends along the entire length of the line a heavy, continuous conductor, thoroughly insulated. This is connected to both ends of each section by fusible plugs or cut-outs and a short branch circuit. The branch circuits of the cut-outs form a Y connection, the main conductor being secured to the stem of the Y and one end of each section to the arms of the Y. It will be seen now that in the normal condition of affairs if current is flowing from one part of the road to another part and there is no train between these two parts, that this current is carried over a double ladder-like circuit. The main conductor carries the major part of the current and the sectional working conductors a smaller part. So long as there is no train on the sections adjacent to any connection, it is evident that there is no difference of potential existing at the two opposite ends of the connecting branch, and no current will flow over it, al-

though very powerful currents are flowing past each end of it. These currents will, of course, be in the same direction. When, however, a train enters a section it does not make any contact whatever with the main continuous conductors, but only with the working conductor, and current is supplied to this working conductor from both ends, partially, it may be, through the working conductors next adjacent, but mainly through the branches connecting it to the main conductor; that is, there is a difference of potential set up in the different parts of this circuit, and parts which were inert before become active the moment a train passes on to a section, no matter whether the train be taking current from the line or giving it to it. The current that flows through these branches may be made to actuate any kind of special device which is necessary, and thus forms a perfect block system of signalling, which operates by the presence of a train upon a section, since this train automatically sets signals at both ends of its section. These signals are of a variety of kinds, visual or audible, or both. Some are day and some night signals; and the incandescent lamp, preferably two or more in multiple circuit with each other, are used for the night signals. Since the current on a motor is under perfect control, it follows that even if the train is at rest on the section, the engineer is able to set his signals.

One of the great advantages of this system of main and working conductors is this: If there is any bad cross or accident on the line the section will be cut out. The rest of the road will not be interfered with in the slightest, but the whole circuit will remain intact with the exception of the one particular branch of 500 or 600 feet, which has been affected. The signals may be made of that automatic character such that when a cross does occur sufficient to break the safety catches of that particular section a signal is set and cannot be replaced until the section is repaired. We have here a perfect safeguard against any extended disabling of the line. Furthermore, if it becomes desirable at any time to operate a signal at only one end of the section, the other end of the section can be cut out. If repairs are made, a section of the road being taken out or replaced, the track foreman can at once cut that particular section out of circuit, and after his repairs are made put it in again without interfering with

the main line. In addition to these devices, the main working conductor can be divided up into sections and switches inserted, so that if it be desirable to cut out any extended portion of the track in case of any accident which makes the passage over a section of the track inadvisable, as in case of a fire, that portion can be cut out without the necessity of disconnecting each individual section.

In addition to these arrangements, the conductors of like potentials on different tracks and switches are connected by cross circuits which tend to equalize the potentials on the

We now come to the question of motor construction. The elevated railroad presents a special problem, as the strength of the superstructure is limited. At present the trains are drawn by locomotives which aggregate about twenty-two and a half tons in weight. Of this weight only fifteen tons is available for traction, this being the weight on the drivers. The weight of twenty-two and a half tons is centred in a very small space. Immediately behind the locomotive is the forward truck of a car with a proportionate weight of nearly nine tons. There is then a total weight of over

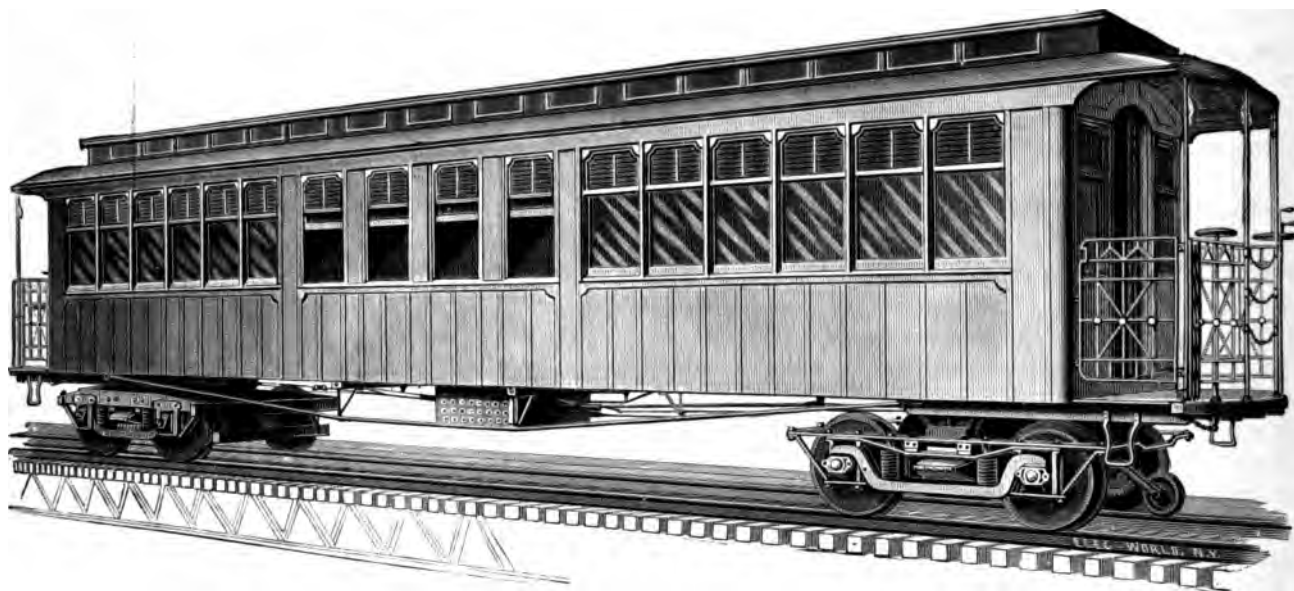


FIG. 170.—SPRAGUE ELECTRIC RAILWAY SYSTEM—ONE-CAR TRAIN.

line, especially where there are any bad joints in the rail, and also when one track is more heavily loaded than the other. Another great advantage of these cross connections is that the current generated by trains running on down grades and stopping, can not only be sent back to the conductor on its own particular track and circulate through the system, but it can take a shorter and more direct path to the opposite track where a train may be moving on the up grade or just starting. It should be further stated that both tracks are supplied from the same source, forming one complete circulating system. All motors are run in parallel circuit with each other, the current in each being independent of the current in all others, and the motors on the one track are in parallel circuit with the motors on the other.

thirty-one tons in a space of about thirty-six feet, which is less than the distance between two columns. The consequence is that the strains, both tensile and shearing, are very great; but these strains are not the only source of danger. The vibration set up by a moving train, both vertical, due to the weight, and longitudinal, due to the motion of the train, has a shattering effect which is very great. It tends to loosen the bolts and badly strains the whole structure. There is an additional vibration due to the reciprocal strokes of the steam locomotive and its consequent unevenness of pull. If an electric locomotive were applied to handle a train, and it were made of fifteen tons weight, it would pull more than a steam locomotive of equal weight, since all of it could be put upon the driving wheels, and there would

be no necessity of additional truck wheels. But a fifteen-ton electric locomotive properly constructed and handled would pull even more than a twenty-two and a half ton steam locomotive with fifteen tons on its drivers. If the weight was distributed on four wheels, the wheels being on two perfectly independent axles, there would be absolutely equal pressure on each. This, however, is not the case with a steam locomotive. In addition to this, the strain could be simultaneously brought on all the wheels of an electric locomotive with such a perfect progression that they would adhere to the rail more firmly than an equal weight

This is the manner in which a single car is now being operated on the Thirty-fourth street branch of the Third Avenue Elevated Railroad in New York city. The accompanying illustrations, Figs. 170, 171, and 172, show the car in one and two unit combination, and in end view, as it appears upon the track. The truck upon which the car is mounted is shown in perspective in Fig. 173, and in detail plan and elevation in Figs. 174 and 174 a.

As will be seen, the latter represent a standard iron truck such as is in use on all the new cars of the elevated railroad, with, of course, some omissions and changes which were neces-

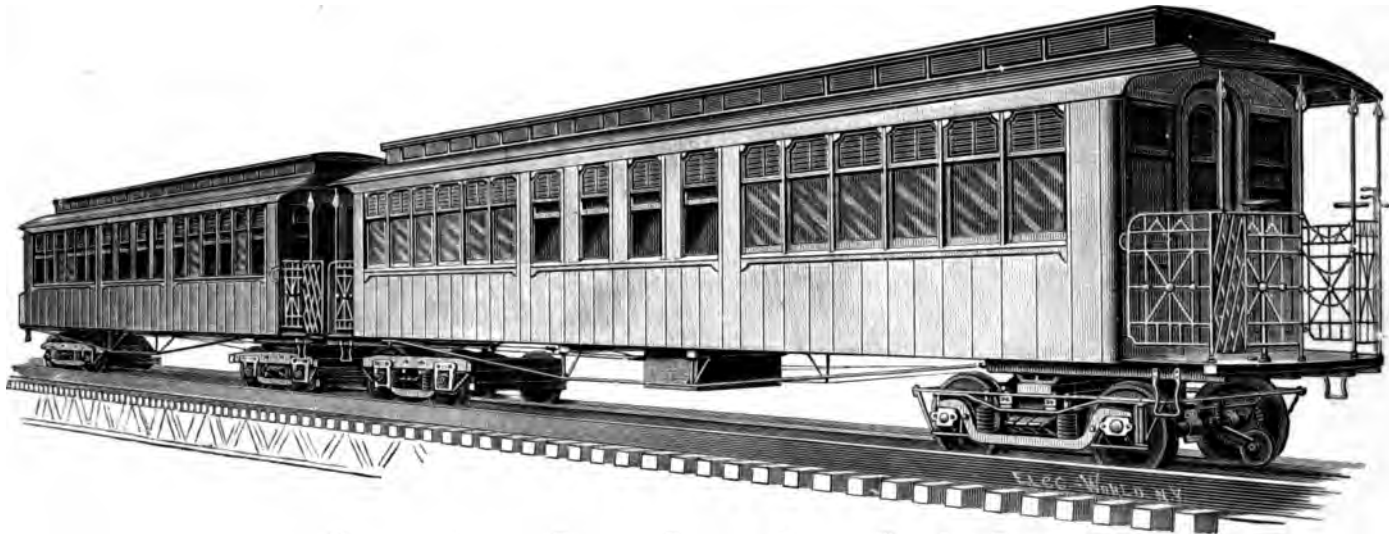


FIG. 171.—SPRAGUE ELECTRIC RAILWAY SYSTEM—TWO-CAR TRAIN.

where the motion is derived from a reciprocal movement. Furthermore, there is a certain amount of increased adhesion of the wheels, just how much it is impossible to say, because it varies under different conditions, and this is probably due to the heating effect of the current passing from the rail into the wheel.

Another method of handling the cars, and this is the most logical, although it may be a somewhat more costly method of working when dealing with old rolling stock, is the placing of the motors underneath the cars on the trucks which carry them. In this way at least one-half of the weight of the car and the passengers, as well as the motors, is available for traction.

If the motors are thus placed under the cars, each can be made an independent unit, or a dozen cars can be operated in a single train by a small regulating truck placed ahead of them.

The principal omission is that of all braking apparatus. There are two motors carried on this truck, each in the space between the axle and the centre cross-piece. The field magnets, which are made of the finest selected scrap wrought iron, are built up of four segments, all forming parts of circles. Two of these form the pole pieces and to these are attached heavy bronze hangers. The latter carry the armature, which is wound on a special modification of the Siemens system, and has at each end forged steel pinions of three inches face, and 3.7 inches diameter on the pitch line. There are thirteen teeth only. The hangers are extended and embrace the axle, which is turned off to a perfectly smooth surface, leaving a small shoulder at each side. Part of the hangers extending from the magnet pole pieces embrace one-half of the

axle, and the opposite half is embraced by heavy bronze caps, and inside each there are split liners to take up the wear. The armature shaft, as it passes through the hanger, is carried by two curved self-concentrating sleeves.

On the axles, close to the hub of the wheels on each side, are two split gears. These differ in character. One is keyed and bolted directly on to the axle, which is first turned off, and is

in these gears is sixty-six; they are of the involute cut, so that if the motor should be moved to or from the axles slightly, the gears will still run perfectly true, with only a little more or less closeness of meshing. The pinions on the armature shaft are set so that the one is half a tooth in advance of the other. Ordinarily, it would be a very difficult matter to get the splines on both the armature shaft and the axle and in the pinion and gears so that they would mesh smoothly when running forward and backward, and it was for the purpose of getting rid of this trouble that the adjustable split gear was designed. It is now only necessary to key the two pinions, one fixed gear, and the web of the other gear in position without any regard to their meshing. The motor is then swung into position, the hangers made to engage the axle, the caps are put on, and the motor being moved forward and backward two or three times while the bolts of the adjustable gear are slack, this gear will assume a perfectly correct position. The bolts are now tightened up and there is thus a nest of double pinions and double gears all meshing with absolute precision, no matter whether the motor runs backward or forward. The method of mounting produces a concentric motion, and by this means the driving and the driven axles are maintained absolutely parallel in two planes under all circumstances.

To allow the motor freedom to follow all the movements of the independent axles over frogs and switches, and also for taking part of the weight of the motor off the body of the axles and to throw it on to the boxes, one end of the motor is suspended at its centre by a bolt passing through the cross girders. This bolt is adjustable, and the upper part is held by a very stiff spring in a state of compression, which spring is in turn supported by a wrought-iron saddle. The motor is then, so to speak, weighed or flexibly supported from the body of the truck. There is also a smaller spring to take up any back movement or tendency to lift of the motor. This suspension is directly in the centre of the pole piece, and the field magnets, which are grooved in the form of a circle, are independently detached from the pole pieces, one of them being put on after the motor is in place.

Because of the relation between the teeth in the pinion and the split gear, it is necessary for

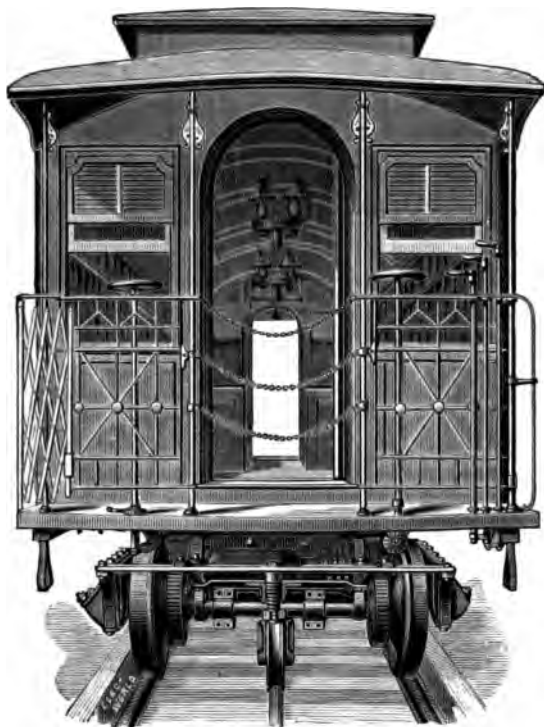


FIG. 172.—END VIEW OF CAR.

a fixture. The other is composed of four parts, two being inner webs which are keyed on to the axle; the two outer ones form the geared section and are bolted together and have corresponding webs projecting inwardly, and fit snugly both on the outer edge and on the face of the webs which are keyed to the axle. The outer and inner webs are held together partially by the method in which they are turned up, but principally by bolts passing through them which work in curved slots. These, then, constitute adjustable split gears, and are probably a new thing in mechanics. The gear wheels are of an especially fine grade of cast iron, and are of the same face as the pinions which mesh into them. The number of teeth

the armature shaft to make sixty-six revolutions before the teeth engage in the same way, and each tooth of the pinion must in turn engage every tooth in the gears. It will be seen also, since the motor is suspended at one end by the truck axle and at the other by compression springs operating in both directions, that whenever the axle is in motion there is always a spring touch, so to speak, of the pinions upon the gears. Barring friction, a single pound of pressure exerted in either direction will lift or depress the motor a slight amount.

1,500 to 2,000 pounds upon each gear. Strain has also been put upon these gears as suddenly as it is possible to close a circuit across 600 volts, and without injurious effect.

This method of mounting motors tends to produce an absolutely perfect form of gear, and has practically obviated the noise which was at first anticipated.

Designs for motors of from 200 to 300 horse power mounted on these same principles will soon be finished, and the motors constructed and put into operation.

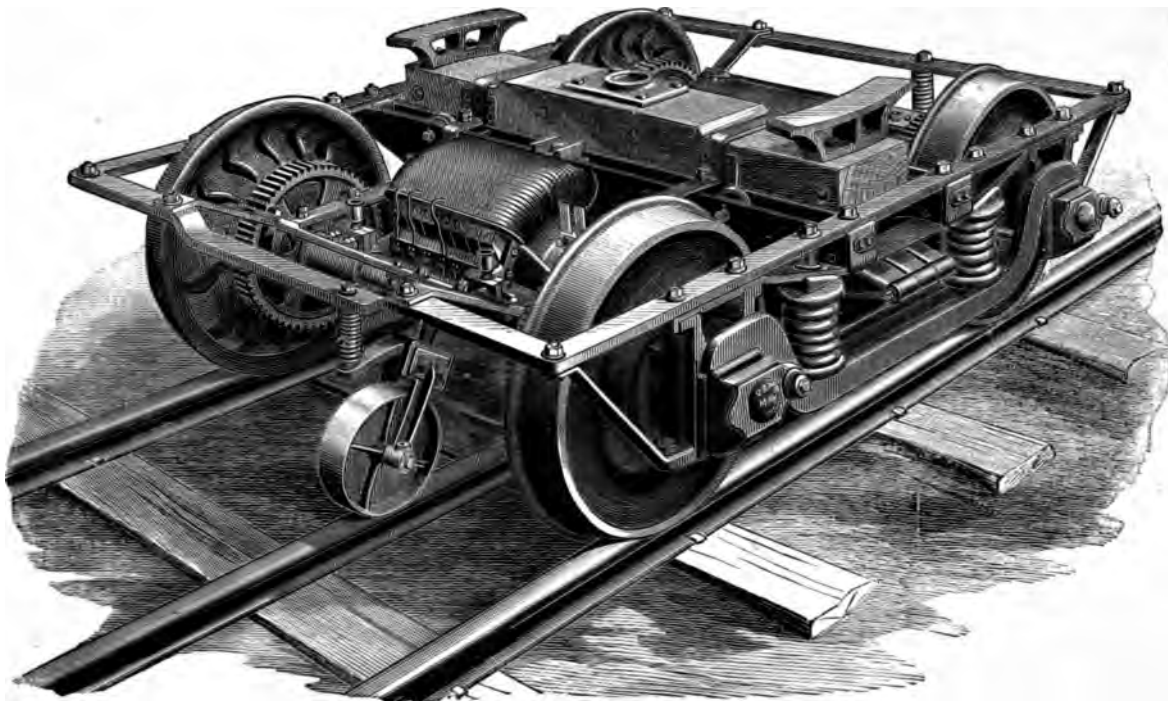


FIG. 173.—TRUCK OF SPRAGUE CAR.

It follows that no matter how sudden a strain, nor how great, it is impossible to strip the gears unless the resultant strain is greater than that of the tensile strength of the iron; because the moment that the motor exerts a pressure upon the gears, at the same instant do the spring supports allow the motor to rise or fall so as to give somewhat, and no matter how sudden the strain is brought upon the gears it is always a progressive one. The result in practice has been that with a weight equivalent to two tons upon each thirty-inch wheel these wheels have actually been skidded in continuous rotation upon a dry track and the strain necessary to do this amounts to from

We now come to the electrical features of the motor. The armatures shown in the illustrations have a special modified form of Siemens winding. The shafts are built up of the finest forged steel, and the body of the armature is built up with alternating layers of tissue paper and very thin iron discs, such as are used in the Edison machine, which reduces the heat loss due to Foucault currents to a minimum. The difficulties first experienced in dealing with currents of such high electromotive force and large volume have now been overcome. The bodies of the armatures are thoroughly japanned and baked, and the utmost precaution is taken in putting on the different coils of wire

to insulate them both from the body of the armature and from each other by the use of a material which offers very high resistance to inductive discharges. The commutators are built of the finest copper, and no insulating material is used other than that just mentioned and fine selected mica.

One of the fundamental features of this system of electrical propulsion is to get rid of all adjustments and to reduce it to the simplest possible system of working and at the same time to maintain as high an efficiency as possible of the motors themselves. For this purpose it was necessary, because of the limited space available, to make the motors of light weight and yet capable of developing a very intense

ly extends over the first third or half of its speed.

3. Variation in the speed of the armature after full potential has been reached at its terminals.

The first characteristic is obtained by bringing the field magnets to a very high degree of saturation. Current is then admitted to the armature under perfect control, and the potential at the armature terminals gradually increased, thus increasing the current until the rotary effort is sufficient to start the train from a state of rest. When the motor is in this condition the torque, or rotary effort, is directly proportioned to the strength of the field magnet and to the current flowing through the armature.

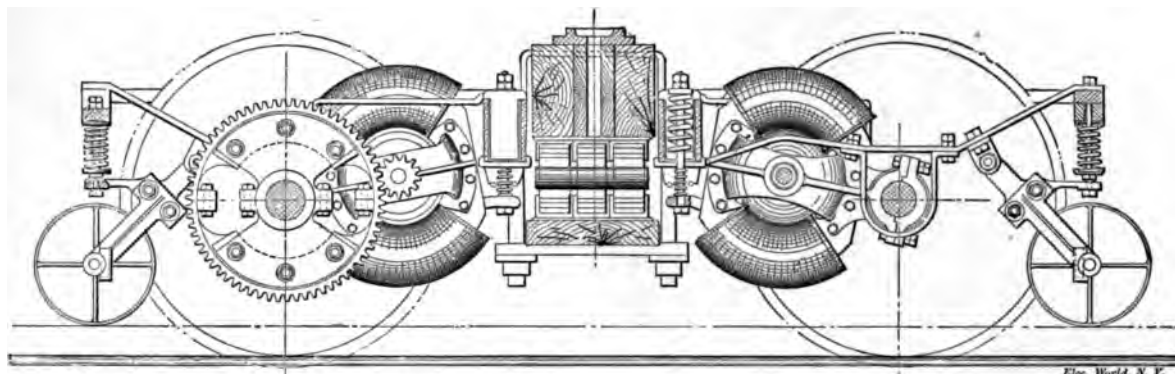


FIG. 174.—ELEVATION OF SPRAGUE CAR TRUCK.

magnetic field. The form adopted for these motors has given these qualities. The motors themselves are built entirely of the finest selected scrap iron specially forged. It was necessary further to have a wide range of speed under full potential at the armature terminals, and hence it was necessary, also, to have a wide range in the magnetic intensity of the field magnets.

A motor when acting in this manner is to be considered under three entirely different conditions:

1. When it is at rest, and it is desired to get the greatest possible torque or tractive effort. This tractive effort should be under perfect control and should necessarily be greater than that which the motor could exert for any very long continued time.

2. When exerting a continuous traction under accelerating speed. This is necessary in getting a train under way, and this effort ordi-

As soon, however, as the armature starts to rotate, a different condition exists. It is now necessary to exert a continuous traction; but the motor, on account of its accelerating speed, is generating an increasing electromotive force of its own which is counter to that of the line, and the difference between this counter electromotive force and the line electromotive force determines the current through the armature. Consequently, it is necessary, while maintaining the field magnet at the same strength, to still further raise the potential at the terminals of the armature by means of which the current is kept at the same strength. It is impossible to maintain a constant tractive effort in any other way under these conditions. The potential will soon equal the initial, and the motor will be doing its maximum work per unit of time. It is now necessary to accelerate the speed of the train, and this is done by weakening the field magnets. This

principle of weakening the field magnets to increase the mechanical effect of a motor at all times when not working up to the maximum was brought out by Mr. Sprague some time ago, when he enunciated the principle, already referred to above.

In a motor with the armature and field magnet independently supplied, the work which the motor will do in a given time, its economy, and

strengthening them. The result is that, if running on a level at a certain speed and a grade is met, and it is desired to get up that grade at the same speed, it is necessary to weaken the field magnets. If the potential falls off and it is desired to keep up the same speed, it is necessary to weaken the field magnets, and, conversely, if it is desired to slow down, it is necessary to strengthen the field magnets.

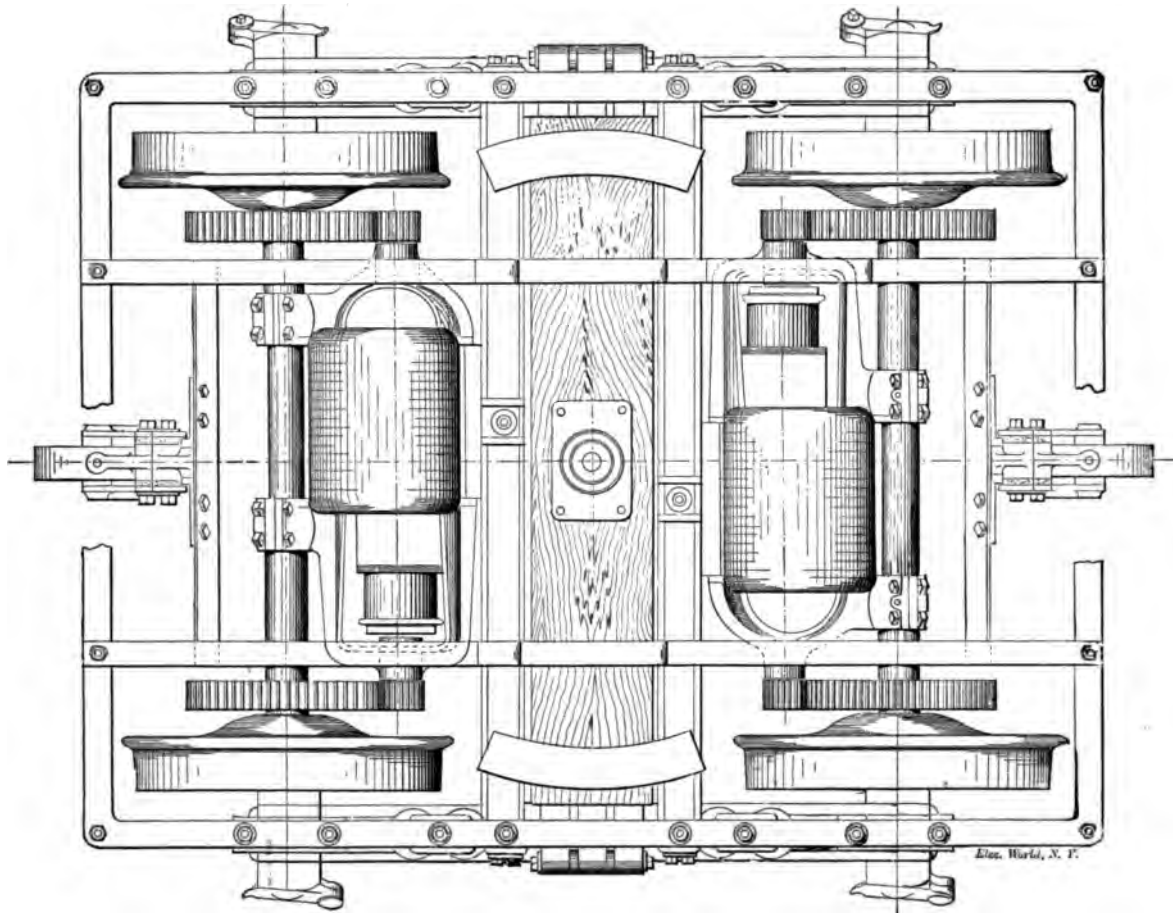


FIG. 174a.—PLAN OF SPRAGUE CAR TRUCK.

efficiency are all independent of the strength of the field magnet, provided the translating devices intermediate between the motor and whatever is the recipient of its energy are not limited as to the rate of transmission of the motor speed; and that in all cases where a motor is working on a constant potential circuit and not up to its maximum capacity, in order to increase the mechanical effect either of speed or power, or both, or to compensate for any falling off of the potential on a line, it is necessary to weaken the field magnets, instead of

A motor, when running, may be considered as a dynamo driven by a current. It generates an electromotive force dependent upon its resultant strength of field and the speed of the armature, and is independent of all other things. It follows that if the field magnet be under proper control, this counter-electromotive force is under perfect control under different speeds, and can be made greater or less in relation to the initial-electromotive force, and consequently the motor can be made to do whatever work is desired of it.

This system of handling a motor, which is an essential departure from previous methods, has been carried out to its logical conclusion in braking the train, as will be indicated later.

The winding of the field magnets of the motors is peculiar. One of the great difficulties which has invariably been met with in working with motors is the change of lead necessary to get the brushes at the point of non-sparking. It is considered necessary when dealing with large powers, if there is going to be continuous and successful running, to maintain the brushes at such a point. This change of the lead, caused by a distortion which is set up by the armature, varies with every change of load, with every change of the armature current, and with every change in the field-magnet strength. It has furthermore been the habit where any considerable power has been developed to use two sets of brushes, one for forward and the other for backward motion. Mr. Sprague has entirely obviated the necessity for doing this by an arrangement which is as simple as it is efficient. This consists in the method of constructing, winding, and connecting up the field magnets. The latter are wound with two sets of coils. One of these is a fine shunt coil which is in series with an independent regulating resistance and produces the normal poles; the other is a coarse coil in series with the armature, which tends to produce poles at right angles to the normal poles, and this circuit is included in the reversing switch, so that when the armature circuit is reversed the current in the coarse coil is also reversed. There are then four poles set up in this machine, two being normal and variable at will, the other two being abnormal, variable poles dependent upon the current flowing through the armature.

In the normal arrangement of circuits, the two sets of field coils, fine and coarse, combine to set up a resultant polar line which is distorted or rotated in the plane of rotation of the armature. Since any increase in the armature current causes the same increase in the series field coils, the tendency to distortion by these two elements will always vary to the same extent, and the resultant position will be always the same no matter what is the extent of variation of current. If the strength of the field magnet is varied independently of the armature, by changing the resistance in the shunt field circuit or by a variation of potential on the line,

while there is a tendency to change the armature distortion, there is an equal and opposite tendency to change the distortion due to the series field coils, and so this, also, has no effect. If the direction of the armature current is changed, so also is that of the current in the series field, and hence the direction of each distortion is changed; but they still oppose each other and vary equally and oppositely as before, and there is still no change in the non-sparking points. It is immaterial whether the change in direction of armature current is due to a change of terminals in changing the direction of rotation of the motor, or is caused in changing the motor into a generator by strengthening the field. Hence, the motor will run in either direction on a circuit of constant or varying potential, with a single or double set of tangential or end-contact brushes, with no change of lead, and, consequently, with no necessity for changing the position of the brushes. The position of the brushes having been once properly adjusted, it is made independent of the amount of work the machine is doing, or the speed at which it runs, or whether it is acting as a dynamo or as a motor. It is likewise independent of the strength of field and of the armature current so long as the magnetic moment of the field sufficiently exceeds that of the armature.

As will be seen from the end view, Fig. 172, there are at each end of the car three vertical switch rods, each connected by movable links with rods running through from one end of the car to the other. These rods have projecting fingers which operate the levers of three very rapidly-moving switches; the movement of these switches is independent of the rapidity of movement of the hand, which simply stores up energy until a certain point is reached, when the lever is freed and the switch thrown over automatically. These three switches are employed as follows: One for breaking the main circuit; another for reversing the armature circuit; and a third for detaching the armature partially from the line and closing it upon a local regulating apparatus. The movement of the handles on the vertical rods are similar at each end. Forward motion of one means forward movement of the car; forward movement of another means closing the main circuit; and a forward movement of the third means also a throwing off of the brake circuit. So that when a man stands at either end of the car,

precisely the same movements mean the same thing as he looks up the track. In addition to these three vertical rods, there is a fourth rod which connects by a bevelled gear with a rod running through underneath the car, and provided with universal joints so as to allow of any necessary adjustment. The top of this rod carries a wheel very much like a brake wheel, and it connects with a regulator which consists of a series of resistance coils. These are so arranged that by the continuous movement of the regulator handle they are first cut out of the armature circuit, while the field is maintained at a high saturation, thereby raising the armature potential, and then cut into the field circuit in reverse manner, thereby weakening the field. This regulator governs also both steps of braking the train.

The current is taken from the centre rail by three conductors, two of which are bronze wheels working on pivoted arms under compression springs. They are provided with adjustable nuts to regulate the tension, and lock nuts to prevent the wheels dropping more than a certain limited amount when leaving the middle rail. The arrangement of contacts is such that the car will span thirty-foot spaces without breaking the circuit. The other part of the circuit comes through the wheels of the truck, so that one part of the apparatus is continually grounded. The collector and the main circuits both run to fusible cut-outs before they reach the main braking circuit, and the armatures are also independently supplied at both ends with similar cut-outs. The armatures and the field magnets are all in parallel circuit with each other.

This is the first instance in which two independent motors have been simultaneously controlled from the same regulating source, and by the methods employed it is perfectly possible to control twenty motors in the same way. When it is considered that the speeds vary from zero to 1,200 revolutions a minute, and the speeds of the two motors should be the same, it will be seen how important a step has been taken. The torque or rotary effort of these motors under slow speeds is very great, and they are able to start from rest and propel two full-sized cars up the maximum grade on the elevated railroad. The motors weigh about 1,200 pounds each.

We come now to the system of braking, which is the logical sequence of the system of control-

ling motors originated by Mr. Sprague. As is well known, when a motor is in operation it is generating an electromotive force. In other words, it is acting like a dynamo, and since this depends upon the strength of the field magnet and the speed, and since the field magnet strength is under positive control, it follows that this motor electromotive force can be made to equal the initial motive force and even to exceed it. When this electromotive force of the motor thus predominates, the machine will become a generator and give current to the line, and its mechanical effects are reversed so that it brakes the train instead of propelling it; and the current generated by it, and the braking power, or reversed mechanical effect, are now controllable by further increasing or re-diminishing the strength of the field, and the new dynamo can now be changed back into a motor instantly at will. The mechanical energy received by the reversed motor and delivered as electricity to the line depends upon the mass of the train and its velocity. In running on a down grade there would naturally be an acceleration of speed, but this method of braking can limit that acceleration at any desired point, or the motor can be slowed down when running on the down grade. This is done, of course, by strengthening the field magnets. Since the energy of the train is now being used to run the motors as braking dynamos, the train will be run at a certain constant speed down grade; or if the field magnets be still further strengthened, the train will slow down; this occurs also in the ordinary process of stopping. The diminution of speed, however, reduces again this motor electromotive force, and hence the field magnet has to be strengthened still further as a train slows, until the speed is reached which, with the strongest field magnet, will give a motor electromotive force equal to that of the line. This point with the motors in question is at about one-third speed, or seven miles an hour. Hence eight-ninths of the energy of a train moving twenty-one miles an hour is sent back to the line in current to relieve the generating station. In fact, the system as here set out has the advantages of a cable road, together with other advantages which the cable road does not possess; because not only do the trains running on down grades help the trains running on up grades, but those which are slowing down like-

wise give up their energy to the system. In fact, this system is one in which trains slowing down and running on down grades supply the current for trains running on up grades and starting, and the central station becomes a differential factor to make up for the loss of conversion and reconversion and to provide for traction and loss in the conductors.

Were the machines perfect converters of energy, this would make the power taken by a system almost independent of grades and stops, and would simply be that necessary to provide for continuous traction and for loss on conductors. Of course, this perfection of conversion can never be reached. It does, however, make a difference of forty per cent. in the power required to operate the electric railroads at the central stations, in the losses on conductors of a given size, and in the investment necessary in the central stations. As a matter of fact, there would be required at the central station only such horse power as is to-day actually developed at any one moment on the elevated railroads, which is only about two-fifths of the capacity of the motors or engines.

Hence, instead of 7,215 ampères of current being supplied from the central stations at two points, it is supplied from as many additional moving stations as there are trains being checked on a down grade and stopping. Sixty per cent. only of this current would come from the main station; that is, 4,329 ampères, or 2,165 from each.

The final step of braking is done by partially detaching the armature from the main line when its motor electromotive force is equal to that of the initial, at which moment there is no current flowing through it, and closing it upon the same local regulating apparatus which is used for regulating the speed and power, and the first step of braking. By this means the train can be brought to a full stop. All these steps of braking are under the most perfect control, but if necessary the braking can be so sudden as to cause the wheels to have a continuous skidding rotation; not such a skidding as is caused when an air brake is put on too hard, but a rotating slip which will be just enough to relieve the armature when the strain on it has come to a certain point. This is the most perfect method possible of braking, because fixed skidding is an impossibility, and the wheels will turn until the train comes to a dead stop, al-

though where the braking power is put on too suddenly and exceeds the grip of the wheels, they will relieve themselves by slipping just enough to keep the braking at the maximum limit.

With the switch in position for the last step of braking, the car can be allowed to creep down the maximum grades at a snail's pace with a movement so slow as to be almost imperceptible.

It is the customary practice to stop at the Second avenue station of the elevated railroad, which is on a ninety-five foot grade, without the use of any shoe-brakes, although the rear truck is fitted with these and can be operated at either end of the car.

By a slight reversal of the armature effort, the car will stand at a dead rest on this grade.

The energy of the train which is expended in the last step of braking can be used in heating the car, and some interesting experiments are now being carried on at the Thirty-fourth street station.

It should be noted that at present the generating station for this experiment is situated on Twenty-fourth street, so that the current at times is carried about three-fourths of a mile. The proper electromotive force is obtained by coupling together five Edison machines in series. The wire used is No. 1 B. W. G., and is carried on the Western Union Telegraph poles. Mr. Sprague has by no means rested satisfied in developing his system of railway and carrying it to the advanced condition in which it now is, but he has been engaged in equipping the station and cars along the line of the road with Edison lamps, which are run in series from the same high constant potential circuit that supplies the car, on a system which has been developed by Mr. E. H. Johnson, the president of the company.

A *résumé* of the special and distinctive features of Mr. Sprague's system may not be uninteresting, and is therefore given below:

A double-track system with motors working in parallel circuit with each other on a constant potential circuit, the two tracks being supplied from the same source and from the same main conductors.

A supply at two or more points by independent batteries of automatically non-sparking machines, the points of supply being maintained at the same differences of potential.

A system of continuous main conductors intersected by switches, and sectional working conductors connected therewith through automatic safety devices.

Means for cutting out, either automatically, in case of accident, or at will, if desired, any portion of the circuit.

An automatic block signal system for day and night use.

Methods for the equalization of potential by cross connections between conductors of like polarity and on different tracks.

A very simple construction of the motor proper.

The centring of the motor upon the axles so as to maintain parallelism between the driving shaft and the driven axle.

The method of flexibly supporting a part of the weight of the motor from the truck so as to allow perfect freedom in following the motions of the independent axles.

The method of doing away with all shock and jar and danger of stripping the gears, and the maintaining at all times of a spring touch so as to prevent any backlash and to insure quiet running.

Double driving from opposite ends of the motor shaft.

The use of fixed and adjustable split gears.

The means for getting a very intense rotary effort in starting by having an intense magnetic field and raising the armature potential gradually.

The means for maintaining a continuous and equal traction until full potential has been reached.

The method of increasing or decreasing the mechanical effects, whether of speed or power, or both, by an inverse varying of the field-magnet strength.

The method of controlling two or more independent motors simultaneously from the same source and by the same apparatus.

The use of a single resistance for both the armature and field circuits, each working independently.

The method of winding to maintain the point of least sparking at a fixed position, independent of the load, speed, or power.

The use of single sets of brushes for both forward and backward motion.

A system of braking consisting in converting the energy of the train into current, which is

delivered back to the line through the same apparatus which propels the car without any reversal of contacts, whereby a saving of at least forty per cent. would be effected in the size and capacity of the generating station, in the conductors, and in the coal and labor expended at generating stations.

The final step of braking by means of which the car is brought to rest through the same dynamic action of the motor while the field magnets are still connected with the line.

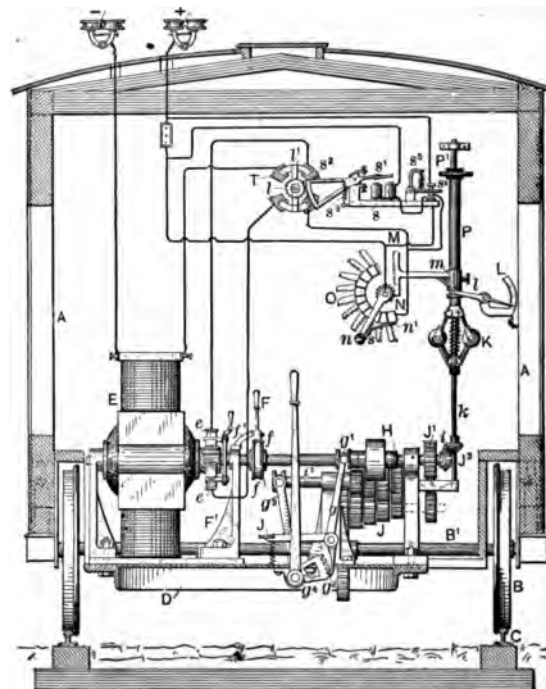


FIG. 175.—HENRY ELECTRIC MOTOR FOR RAILWAYS.

The method of lighting cars and stations from the main station.

The method of heating cars with a part of the energy of the momentum.

Another of the workers in the field of electric railroading is Mr. John C. Henry, of Kansas City, who has been busy for some time past in elaborating a system which possesses several novelties and is now going into use. Without entering into the various methods employed by Mr. Henry in distributing and taking off the current from the conductor, either overhead or underground, we will only describe the locomotive car itself and its arrangement. This is shown in Figs. 175 and 176, which represent respectively a transverse sectional view and a plan of the car.

The principal objects aimed at in its construction are to make each motor automatically adapt itself to every change in load and grade, and to afford safety devices by which no injurious effect could be produced through abnormal conditions of working. Mr. Henry has also adopted an arrangement by which the motor is kept at a constant uniform speed, irrespective of the speed of the car.

As will be seen by the illustrations, the motor is mounted on a frame *D*, which permits a direct connection to be made with the axle from the driving shaft of the motor *E*. For the pur-

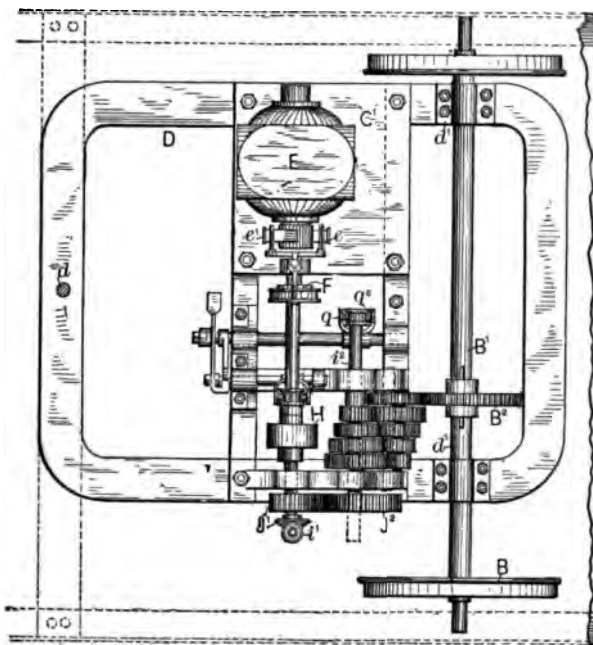


FIG. 176.—HENRY ELECTRIC MOTOR FOR RAILWAYS.

pose of automatically controlling the supply of the current to the motors, the driving shaft *G* of the motor is connected by the bevel gear *i* with the upright shaft *k*, carrying the governor *K*. A sleeve *P*, on the shaft *k*, is attached to the governor at one end, and from the sleeve there extends an arm *m*, carrying the rack *M*, which gears with the pinion *N*. Encircling the latter is a series of resistance coils *O* in electrical connection with the main conductors through brush *n*¹ and lever *n* and branch conductors. When from any cause the speed of the motor shaft varies from the prescribed limit, the rack *N* is drawn up or down by the governor *K*, which moves the contact brush *n*¹ over the commutator of the resistance coils, increasing or decreasing the resistance to the current.

For the purpose of automatically reversing the poles of the motor, the two opposite poles of the switch *T* are connected to wires running

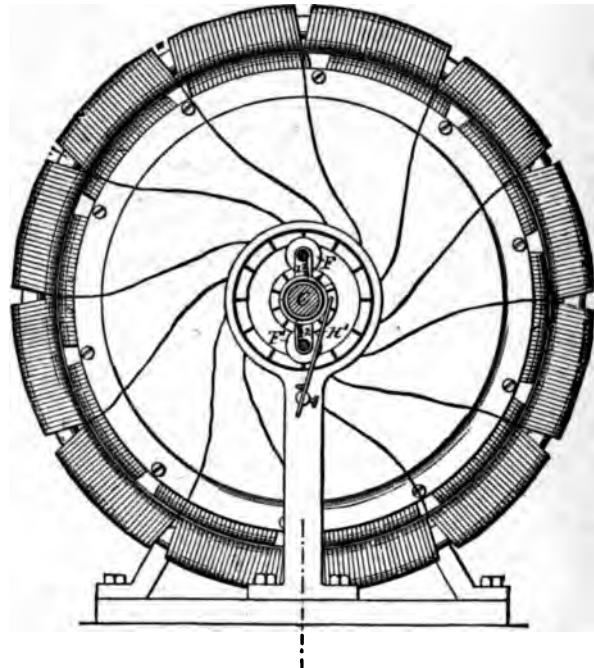


FIG. 177.—SIDE VIEW, HIGHAM MOTOR.

to the motor field and to the commutator brush *e*. A segment rack lever *s*² gears with the pinion of the switch, and a spring *s*³, attached

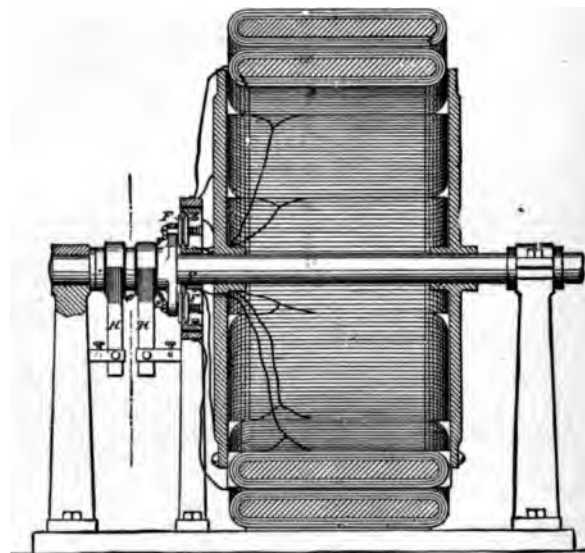


FIG. 178.—SECTION, HIGHAM MOTOR.

to the lever, keeps the rack in one position under tension. The opposite end of the lever *s*² is provided with the armature *s*¹, and in the

field of the electro-magnets s . Two short circuits extend from branch conductors in electrical connection with the magnets s . A circuit closer s^6 is also provided, the key of which is held in a horizontal position by means of a spring s^5 . The electro-magnet s is also connected to the circuit closer. With this arrangement, should the shaft of the motor attain a rate of speed above that necessary to propel the car, the governor is thrown out, thereby drawing down the sleeve P , and the projection P^1 depresses the key of the circuit closer s^6 , the

terlocking device is held by pins q^6 . The lever g extends from the shaft G to the lower part of the supporting base to the speed gearing, to which it is pivoted. One part of the lever is extended at right angles as a foot lever, and a short portion g^2 extends downward and is tapered at right angles, so as to engage with the gear-sector g^4 , which is pivoted to the frame D . A hand lever extends vertically from the gear-sector g^4 , to which it is attached, and a lever g^3 is attached to the same point, and also in rigid connection with the hand lever, and is connected

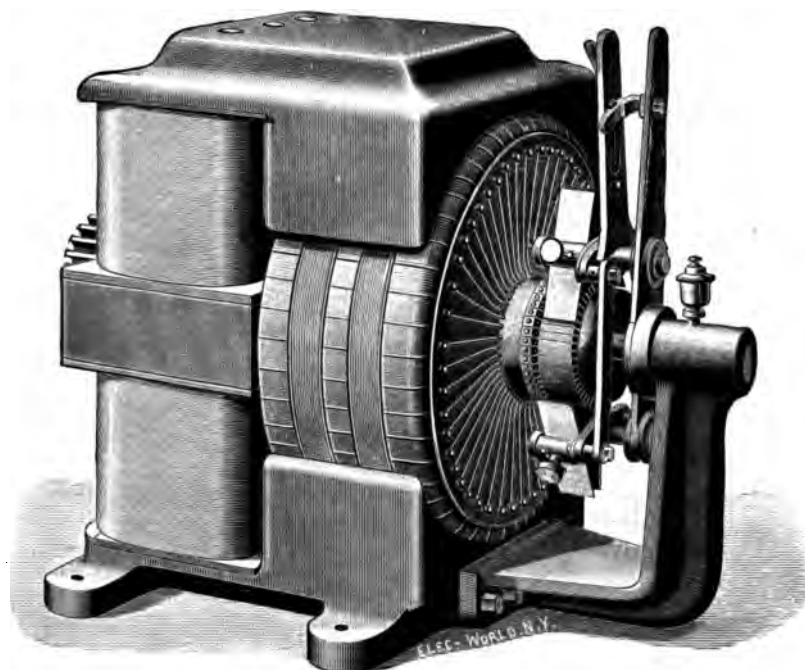


FIG. 179.—PERSPECTIVE, VAN DEPOELE STREET CAR MOTOR.

magnets s become excited and draw down armature s^1 on lever s^2 . This rotates the pole changer T , which changes the polarity of the motor and allows it to generate instead of drawing upon the current. When the poles of the motor are reversed and the motor is acting as a generator, the current is shunted from the resistance coils through a leak circuit, the circuit being made through the circuit closer s^6 . The speed of the motor is indicated by means of the needle l on the indicator L .

The driving shaft G of the motor is provided with an intermediate friction-clutch H , placed in connection between the motor E and gear J^2 . One portion of the clutch H is provided with a neck g^1 , in which the end of lever g of the in-

terlocking device is held by pins q^6 . The lever g extends from the shaft G to the lower part of the supporting base to the speed gearing, to which it is pivoted. One part of the lever is extended at right angles as a foot lever, and a short portion g^2 extends downward and is tapered at right angles, so as to engage with the gear-sector g^4 , which is pivoted to the frame D . A hand lever extends vertically from the gear-sector g^4 , to which it is attached, and a lever g^3 is attached to the same point, and also in rigid connection with the hand lever, and is connected

with the end of the reciprocating plunger i^2 , which is reciprocated in the direction of the speed gearing and for engaging the gear. Thus when it becomes necessary to change the speed of the car or change the relation of the gear without checking the speed of the motor-shaft, the foot lever is operated to throw the friction-clutch H apart. This releases the end g^2 of lever g from the gear-sector g^4 and the hand lever is then operated to throw the plunger in or out of connection with the various gears. The gear J^1 on the shaft meshes with gear J^2 , and the gear J^2 is mounted upon the same shaft i^2 as the speed gearing, which in turn communicates power to the gear B^2 , attached to the axle B^1 .

While all these arrangements are by their nature designed to be more or less automatic, Mr. Henry has also introduced devices for reducing the rate of speed when required by means of the ribbon brake *F*. It is further evident that the contact brush of the resistance coils may also be moved by hand for starting, checking, or reversing the motor.

In the early part of this work, mention was made of the Elias motor in which two electro-magnetic rings, one within the other, acted as a motor by mutual attraction and repulsion. The same relative arrangement of armature

coils of both the electro-magnetic rings, there splitting and passing in opposite directions through opposite halves of each ring of coils and out through the contact wheel *F'* and brush *H'*. Thus the travelling contacts rotate the polar points of both electro-magnetic rings in the same direction as that in which the rotary electro-magnet moves mechanically and, as a result, it is said, the power developed by the motor is increased.

We have already in Chapter VII. drawn attention to and described the electric railway work accomplished by Mr. Van Depoele in his equipment of the lines at Appleton, Wis., Montgomery, Ala., and in other places, but without special reference to the type of motor employed for that purpose. Hence a description of the latter will now be of interest.

The motor which is illustrated in the accompanying engraving, Fig. 179, has an armature of the well-known Gramme ring form, and the shaft rests in bearings, one of which is a bracket bolted to the lower pole piece, while the other is the neutral point of the field magnets. Having special regard to the attainment of compactness, the field magnets are given the form shown. It will be seen that the field coils are wound on the two sides of a cast-iron upright upon the ends of which are bolted the pole pieces which project at right angles and encircle the armature.

As the direction of travel of the car must be under control, two pairs of brushes are provided by which the direction of rotation of the motor can be changed at will. Each pair of brushes is attached to a brush-holder provided with a lever, by the shifting of which either pair can be brought in contact with the commutator. The end of the armature shaft carries a gear wheel, which meshes into another attached to the car axles.

In order to provide for the regulation of the motor so that it may run at different speeds, and without the use of external resistances, Mr. Van Depoele adds to the ordinary field-magnet coils additional ones, which are successively connected to each other in series and are also in series with the main field coils. This is shown diagrammatically in Fig. 180, which represents the method adopted for the automatic regulation of the motor. It will be seen that the coils a^1 , a^2 , etc., are brought out

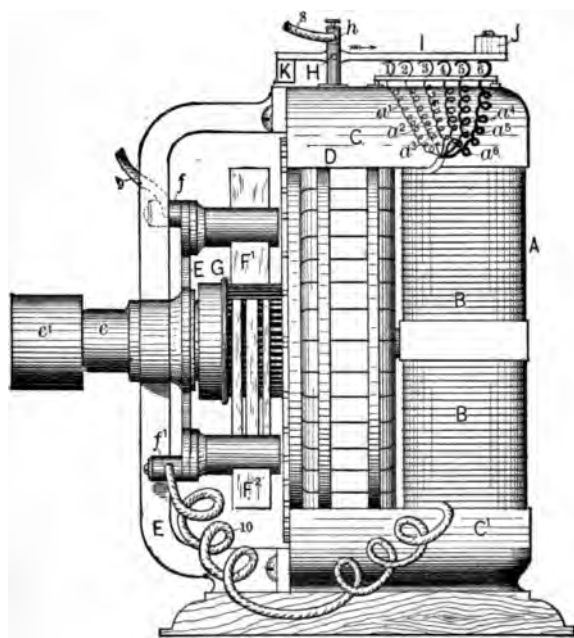


FIG. 180.—VAN DEPOELE MOTOR.

and field has been adopted by Messrs. E. T. Higham and Daniel Higham, of Philadelphia. They have, however, introduced modifications which are designed to improve the efficiency of the arrangement.

The motor is shown in side view and in section in Figs. 177 and 178, and will be seen to consist of two ring magnets of the Gramme type. The inner magnet revolves while the outer remains stationary, but both are provided with commutators. The current coming in, say at the brush *H*, passes through the contact wheel *F* to the commutator-plates with which they happen to be in contact, and thence through the corresponding conductors to the

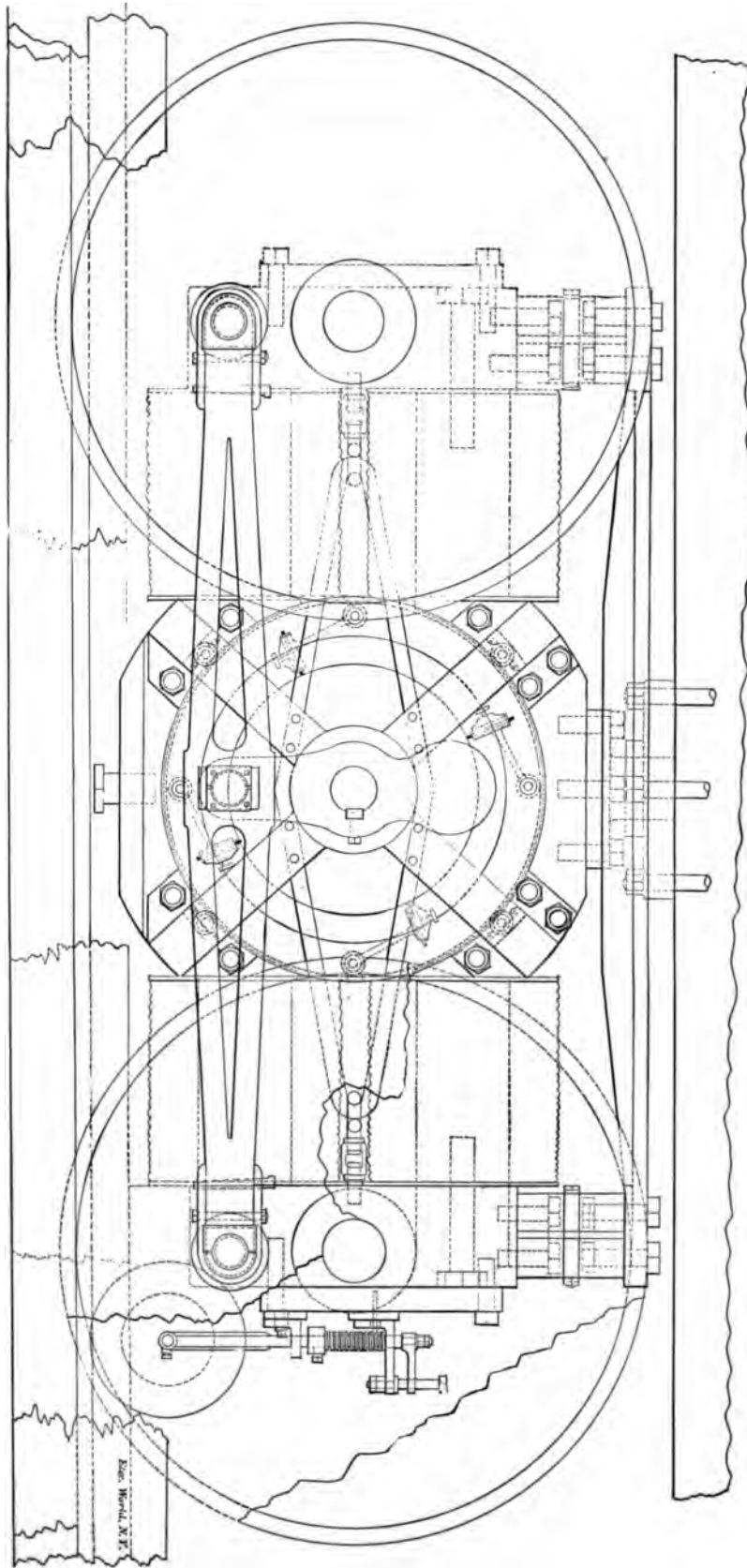
to spring terminals over which is placed a contact bar *I*. One end of this bar carries an adjustable weight *J*, which tends to press down on the terminal, 1, 2, 3, etc. The other end of the contact bar is provided with an iron armature *K*, in close proximity to the surface of the pole piece *C*, so that when attracted by the magnetic condition of the latter the other end is drawn away from the contact springs, thus cutting out the resistances.

This arrangement, shown in Fig. 180, is evidently intended for motors in which it is desired to keep the current and speed constant. But in the motor shown in Fig. 179, which is applied to the street cars where these conditions do not prevail, a system of hand regulation has been adopted. The auxiliary field coils are connected to a commutator which is manipulated by hand, and by means of which any speed from rest to maximum can be obtained.

We have in Chapter VI. made mention of the early work of Mr. Stephen D. Field, in the domain of electric railroading. His most recent work now deserves mention here as it is marked with the usual originality of the inventor, and is on the eve of practical demonstration.

Being, like others, impressed with the special applicability of electric motors to the propulsion of the cars on the elevated railroads in this city, and encouraged in this project, we believe, by his uncle, Mr. Cyrus W. Field, Mr. Field has for some time past devoted his special attention to the problem involved, and has so far matured his plans that

FIG. 181.—MOTOR AND TRUCK FIELD SYSTEM—SIDE ELEVATION.



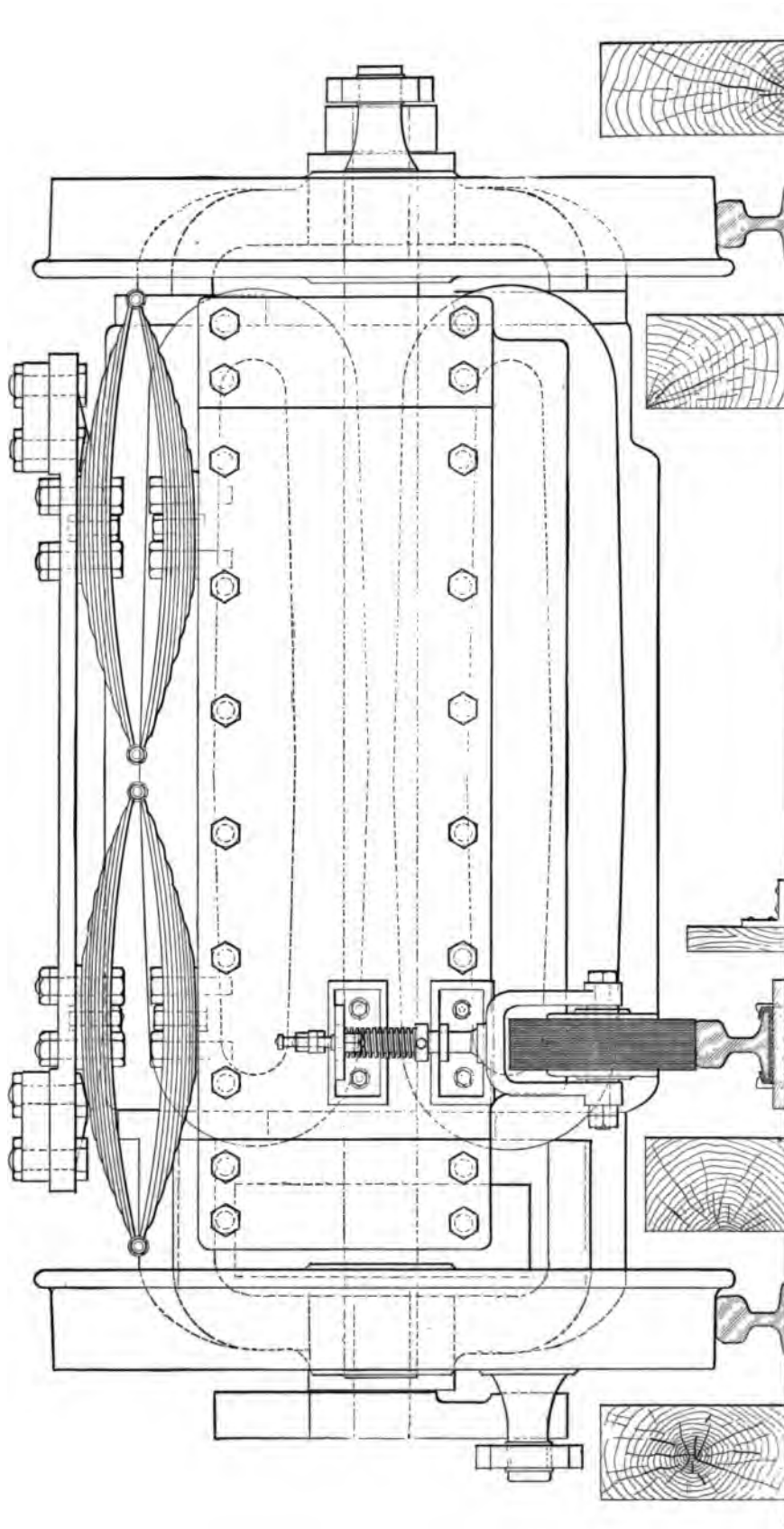


Fig. 182.—MOTOR AND TRUCK, FIELD SYSTEM—END ELEVATION.

actual work of construction is now progressing, looking to a practical test.

Taking in review the mechanical details first, it will be seen that between the wheels of the car truck a single motor is situated, the armature shaft of which is connected directly to the wheels by means of a crank and side connecting-rod similar to that employed on steam locomotives. This is clearly shown in Figs. 181 and 182, which represent, respectively, a side and an end elevation of the truck as it is being constructed. The cranks, as shown, are, for obvious reasons, keyed to the armature shaft at an angle of ninety degrees.

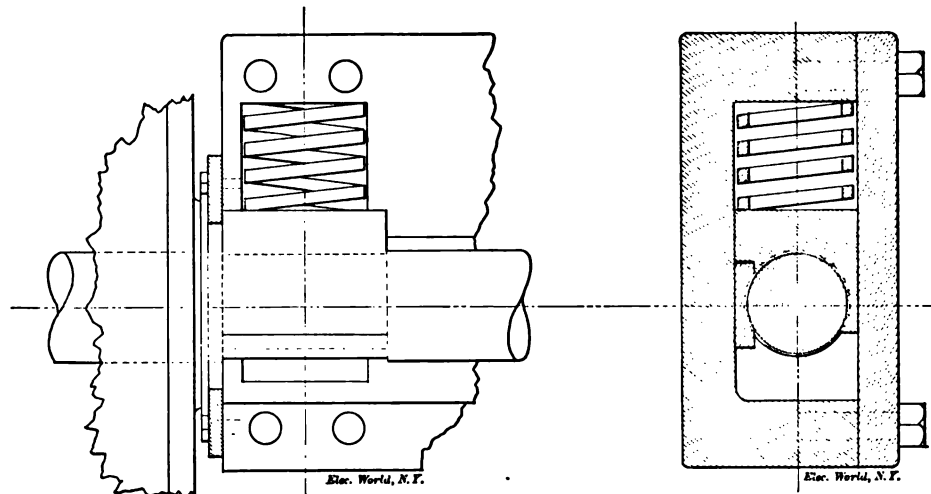
The manner of suspension of the motor is clearly shown in Fig. 181. The upper and lower field magnets, which form consequent poles, are held together by the usual iron connecting pieces or yokes, and through each of these passes an axle of the truck, so that the entire weight of the motor is equally distributed on both axles. The bearing, however, is not a rigid one. Although, as stated above, the axles pass through the yokes of the field magnets, it will be observed, Figs. 183 and 184, that the latter are made up of two pieces, or perhaps, to put it more correctly, that a cap is bolted to the real

connecting piece at each end. Fig. 183 shows the bearing in end elevation and part of the adjoining wheel; while Fig. 184 is a sectional view which shows the usual spring interposed between the weight and the bearing. The cap maintains the spring and bearing in position and allows the motor free vertical motion without strain, due to inequalities in the road-bed.

The armature turns in bearings formed by the junction of four brass arms on each side of the armature, and these arms are in addition bolted to braces on each side, which converge and are joined to the connecting piece of the

vice will be understood from the illustrations, Figs. 181 and 182, which show the contact wheel held by brackets bolted to the yoke of the field magnet.

The wheel itself is built up of alternate layers of discs 6 inches and 9 inches in diameter, of thin spring brass, so that each large disc is flexible, and in bearing upon the rail can be given a bending motion. It will be noted, at the same time, that the forked rod supporting the wheel passes through two brackets, above the upper one of which is a lever attached to the rod. This lever can be swung through an arc of 180 degrees and can be clamped in any position;



FIGS. 183 AND 184.—BEARING OF MOTOR ON CAR AXLE.

field magnets by means of bolts and turn-buckles. In this way all horizontal motion of the motor relatively to the truck is prevented, while at the same time its vertical motion is not restricted.

The body of the car rests on springs, which are bolted to the tops of the yokes, the king-bolt fitting into a bearing bolted to the centre of the upper pole piece.

There remains still another mechanical detail to be described, and that is the manner in which the current is taken from the central insulated rail. It is well known that dirt and rust not infrequently cause defective contacts and introduce resistance into the motor circuit. To guard against this, and in order to insure good contact under all conditions, Mr. Field has designed what may be called a combined contact wheel and brush. The nature of the de-

the position of the contact wheel relative to the rail corresponding to that of the lever.

Now, it will be readily understood that when the lever is in the middle position on the arc, the wheel stands as shown in Fig. 182, and only a rolling contact is maintained between wheel and rail. But if the lever should be turned slightly to either side, so that the discs are no longer parallel to the rail, a slight rubbing or scraping motion would be added to that of the rolling. By turning the lever still more and increasing the angle, the rubbing component, as it were, can be increased to any desired extent until, when the lever is at an angle of ninety degrees from its original position, the wheel stands at right angles to the rail and, obviously, rubbing alone can take place. The wheel being built up in the manner described above, acts as a resilient brush, taking off the current

and keeping the rail clean. It is evident that this brushing action need only be resorted to when necessary, the wheel otherwise taking up the current by the rolling contact, a spiral

automatically at the non-sparking points. The reader will have noticed in Fig. 181 that four brushes are shown bearing on the commutator, but for the sake of clearness only two are

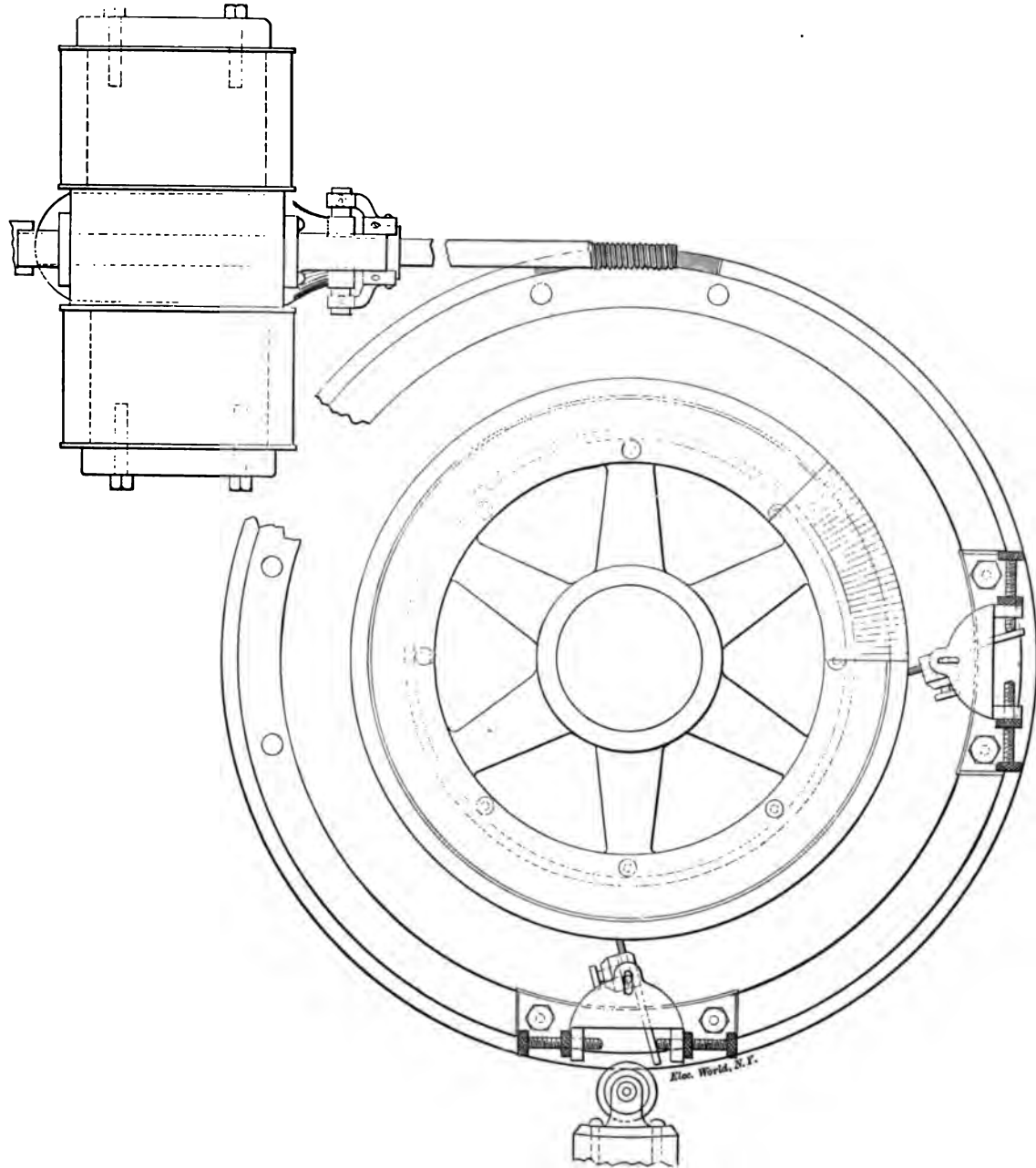


FIG. 185.—REGULATING MOTOR AND ADJUSTABLE BRUSHES.

spring being provided which presses the wheel upon the rail.

We come now to the electrical details, taking up first the manner in which the motor is regulated and the brushes are maintained auto-

shown in Fig. 185, one each of the horizontal and vertical pairs. The office of the auxiliary brushes will appear presently. The brushes are all mounted upon a ring, on the outer periphery of which screw gear teeth are cut, and

into which meshes a screw which forms the end of the armature shaft of a small motor.

The horizontal pair are the main brushes, while the vertical pair are what may be called the regulating brushes. The field of the regulating motor is connected in shunt to the armature of the large main motor, while the armature of the regulating motor is connected to the regulating brushes.

From what has just been said, it will be evident that when the normal amount of current passes through the motor, the regulating brushes bear upon the commutator at points of equal potential, and hence no current passes through the regulating motor. Now if while in this position any change of load or speed occurs, the diameter of commutation would be changed, and the regulating brushes not yet having changed their position, would bear upon points between which there now exists a difference of potential. This evidently would cause a current to pass through the regulating motor, which would be started revolving in a direction corresponding to the change of conditions. The turning of the little motor gearing with the ring causes all the brushes to be shifted simultaneously until the regulating brushes reach again points of equal potential, when evidently the little motor stops for want of current. The main brushes will at the same moment have arrived at the proper diameter of commutation. In this way the motor accommodates itself automatically to changes of load or speed.

There are several details in connection with this regulating device which are also worthy of notice. By referring to Fig. 186, it will be seen that while the lower main brush bears against the inner end of the commutator, the small regulating brush bears at the outer end. It will further be noted that only every fifth commutator bar is continuous, the four intermediate ones being divided near the outer end. One of these intermediate bars is shown in section in Fig. 186. The outer end is entirely insulated, and hence receives no current whatever from the motor; the insulated pieces thus serving merely as a continuous bearing for the regulating brushes. From this it will be seen that while, as usual, the main brushes are in continuous electrical contact with the motor, the regulating brushes only make contact at every fifth commutator bar. In this way the

regulating motor is caused to act under short impulses of current. The effect of this is that while the regulating motor is started promptly, it comes to rest very quickly when the brushes reach the neutral point where they should remain, and thus they are prevented from travel-

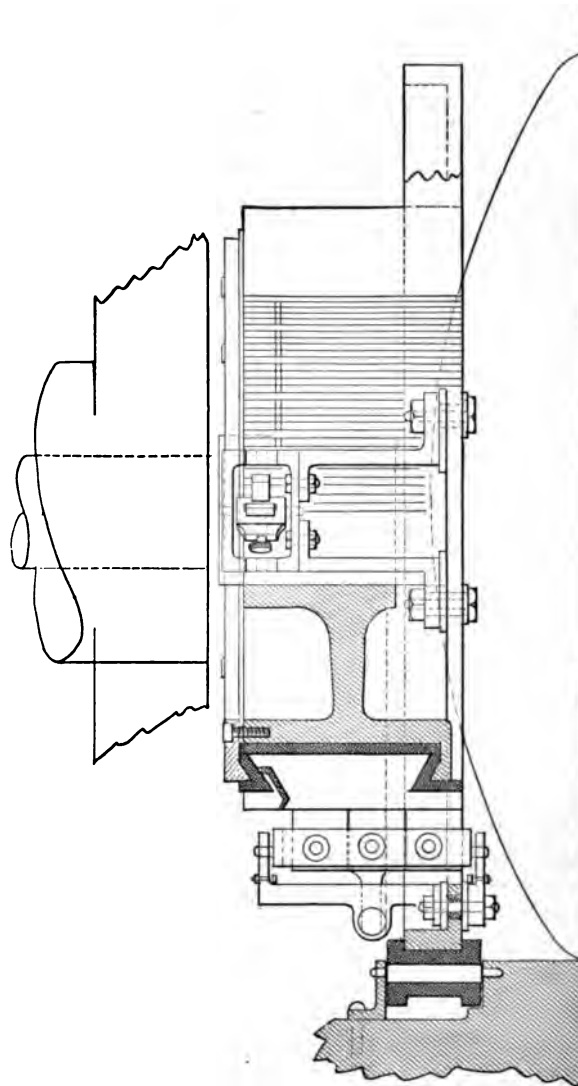


FIG. 186.—DETAILS OF COMMUTATOR.

ling beyond that point by the momentary impulses which otherwise would immediately send reverse currents into the motor.

The brush-holders being rigidly attached to the ring, some provision must be made for guarding them against injury, as they bear almost vertically against the commutator. This is accomplished in a manner shown in Figs. 185, 186, and 187, which give different views of

the brush-holders. The brushes, as will be seen, are held in a clamp provided with pivots which slide in slots in the holder, the brushes being pressed toward the commutator by two springs. Now, when the direction of rotation of the armature is reversed, the brushes are pushed inwardly a short distance and then carried over until their angle of bearing is reversed, the motion being limited by the stop screws shown; then the springs again press the brushes against the commutator as before.

In addition to the automatic method of regulation above described, resistances are provided and a reversing lever, so that the strength of current and the direction of rotation of the motor can be regulated at will. The lever is so arranged that it cannot be reversed as long as there is any current in the motor.

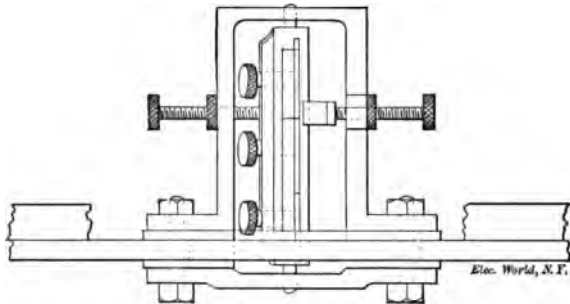


FIG. 187.—DETAILS OF BRUSH-HOLDER.

Another feature is the electrical brake, which may be applied at will and to any degree of pressure. The current operating can be regulated by a resistance switch. The switch is so arranged that at the last section, when the brake is to be taken off, a reverse current is sent into the brake coils by means of an induction coil or condenser placed in the circuit; this momentary reverse current instantly demagnetizes the brakes, so that they fall away freely from the wheels.

These points comprise the essential details of the Field motor arrangements. The work of construction is now actively going on, and within a short while a practical trial will be made on the elevated railroads of this city.

Mr. Field has, however, looked farther abroad than the city in the application of electric railroads, and is elaborating plans for an electric locomotive designed for rapid suburban transit. Our illustration, Fig. 188, shows the general design of a locomotive and baggage car com-

posed. It is proposed to employ six-foot drivers coupled direct to the armature shaft. The machine is to be a four-pole Gramme, with an armature of four feet in diameter, and a speed of from thirty to forty miles an hour will be attainable.

For several months past an electric railway has been in operation on Ridge avenue, Philadelphia, running for a distance of about two miles, and having one terminus at the Laurel Hill Cemetery. This line was constructed by the Union Electric Company, under the direction of Mr. W. M. Schlesinger, and has been in daily successful operation.

In order to avoid overhead conductors and also the use of the rails as conductors, the mains have been placed in a conduit having a slot at the top for a lever which leads the current from the conductors to the motor on the car, Fig. 189. In designing the conduit, it was found inadvisable to cut through the cross-ties of the railroad, as these form in most cases the foundation of the track. Practical experience has proved that a small conduit having good sewer connections answers all purposes. The main conduit is therefore only 9 inches deep by 5½ inches wide. It is built in sections of from fifteen feet to twenty feet, of heavy channel iron resting on the cross-ties; substantial cast-iron wedges, resting also on the cross-ties, hold the two sides of the conduit at the proper distance from each other at the bottom and leave an opening ¾ inch in width between the lower flanges. To the sides of the channel iron, at proper distances, small angle irons are riveted to keep the slot of the conduit at the proper size. Braces are attached to the angle irons which pass through either cross-tie or stringer and are provided with nuts by means of which they can be tightened or slackened at will. An auxiliary conduit is put down below the cross-ties, built either of wood or cement. At convenient places this connects with large manholes at the sides of the track, and these again communicate with the sewers. Water and small particles of dirt fall through the opening made by the wedges between the channel-iron into this lower trough and pass from them to the manholes and sewers. But to prevent any accumulation in the upper conduit, this opening is at proper intervals increased to five inches by cutting away a part of the lower flanges of the channel iron.

The greatest difficulty experienced with underground conductors is to protect the insulation of the conductors from water and dirt. To accomplish this in the present conduit, an angle iron is riveted to the top flange of the channel iron in such a manner that one of its flanges, pointing downward parallel to the main side of the channel iron, forms one side of the slot. In the inverted trough formed in this manner the conductors are fastened, so that the contact side, *i. e.*, the side on which the pieces rub, is the lower side. The conductors are much narrower than the trough, so that contact with its sides is impossible. Dirt or water coming in through the slot will, there-

the latter is furthermore to protect the copper from wear. The connection between the conductors of two following sections is made in boxes outside the conduit. At proper intervals, the top of the conduit is made removable, giving access to the inside. These traps are also put at every place where a connection is made with a manhole. As in opening these traps, the top plates are often handled roughly and thrown in the dirt, they are not provided with conductors, but in place thereof wood is fastened to them. The current is carried round them through insulated wires. This also prevents interruption of traffic in case of the opening of a manhole.

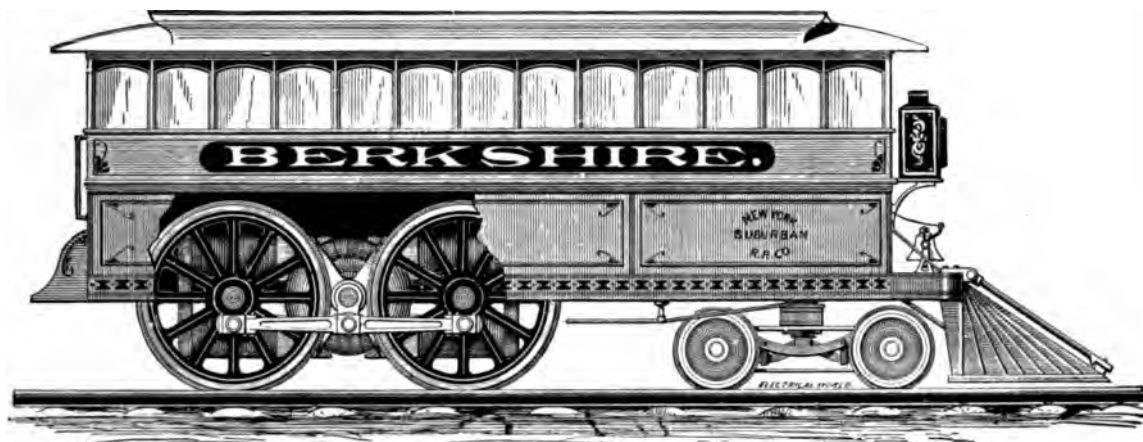


FIG. 188.—THE "BERKSHIRE" ELECTRIC CAR.

fore, also fall to the bottom of the conduit without interfering with the insulation.

The conductors are made shorter than the sections, and the trough is closed at the ends of the sections by means of a block of wood or other insulation, the lower side of which is in the same horizontal plane with the lower side of the conductors. These latter end within about $\frac{1}{4}$ to $\frac{1}{2}$ inch of these blocks. In this manner the insulation is protected from any dirt or water coming in between the sections.

All sections are made exactly the same size, so that if one is damaged it can easily and quickly be replaced by another.

The conductor itself is a copper bar, to the lower surface of which a small angle iron is fastened. The contact pieces rub along the iron and are prevented from leaving it by the downward flange of the angle. The object of

All connections between the conductors of following sections are easily accessible, so that in case of damage to one section this can easily and without interfering with the conduit be cut out of the circuit and the current taken round it by means of insulated wire. As the sections are only twenty feet long at the utmost, the momentum of the car will easily carry it over the gap. As all motors on the cars are in multiple arc, no complicated make and break appliances are required in the conduits, and as the conductors on either side form one continuous line, testing for insulation and continuity can easily be done from the station. To convey the current from the conductors in the conduit to the motor on the car, each of the latter is provided with specially constructed frames, so arranged as to make the contact pieces perfectly independent of the oscillations of the car or any variation in the distance between the body of

the car and conductors, caused either by varying loads on the former or uneven construction of road-bed. In designing these frames great care has been taken to combine simplicity with strength, the vital parts being well protected by strong cast-iron or phosphor-bronze frames. On the road now running in Philadelphia it has happened several times that large paving stones were placed intentionally at night on the conduit, but they were invariably thrown

ward; and by moving the lever more or less from the central position, the speed is increased or decreased. If desired, levers can be placed on both platforms, the one not in use being secured by means of a lock.

To allow the motor to start up easily and rapidly, the field magnets are in a separate circuit which is not opened when the car stands still. The motor brushes are tangential, one pair only being required. They are connected

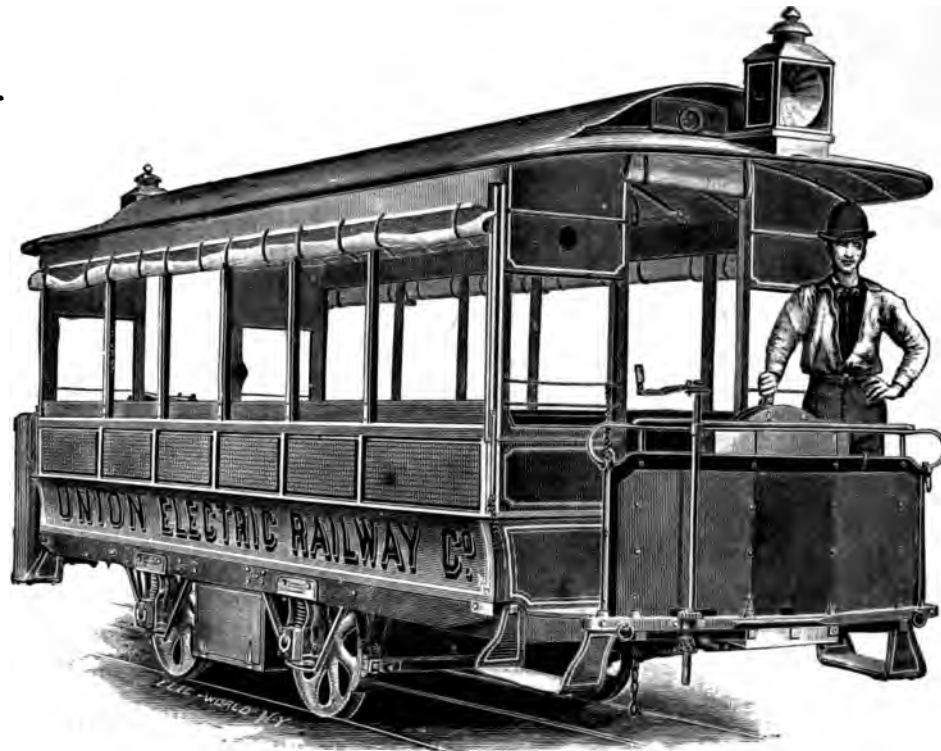


FIG. 189.—THE SCHLESINGER ELECTRIC CAR.

to one side by the frames without doing the slightest damage. Steel springs are used as contact pieces, a very steady and good contact being thus obtained, as shown by the ammeter.

The motors are attached to the cars in such a manner as not to interfere with the seating capacity. They are placed beneath the body of the car between the axles, and specially constructed chains transmit the power from the armature to the wheels. The car is operated by means of a single lever on the front platform. When the lever stands in the middle position, the current to the armature is interrupted, and the motor naturally stands still or gives no power. On moving the lever to the right the car runs forward; to the left, back-

ward; with the lever in such a manner that the same motion by which the current through the armature is reversed also sets the brushes. Aside from the hand brakes, each car is provided with electric brakes of the simplest construction. The interior of the cars is lighted by incandescent lamps, deriving their current from the same source that propels the motor; and electric gongs complete the outfit.

Among the most prominent of the electric motors in general, practical use is the Edgerton, designed by Mr. N. H. Edgerton, of Philadelphia, and shown in perspective in the accompanying engraving, Fig. 190.

The pole-pieces, Fig. 191, are arranged each with three radial cores, on which the exciting

coils are wound, and by which the fields are supported on the interior of a cylindrical iron shell which forms the framework of the motor, as well as the yoke-piece of the field magnets.

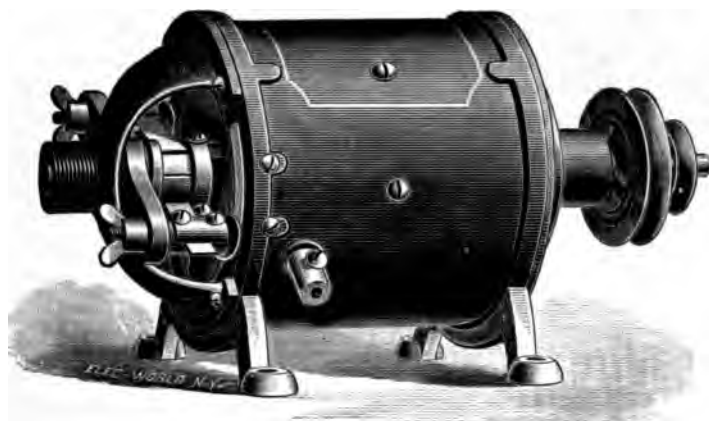


FIG. 190.—THE EDGERTON MOTOR.

The shell and pole-pieces form a concentric cylindrical structure in the interior of which the armature revolves on a central shaft supported at either end by bearings situated centrally in the end caps or lids. These end caps may close the cylinder entirely or not, but usually one end is closed completely while the other is left open, as shown, for easy access to the brushes and commutator.

The armature shown in section in Fig. 191 is polar, and consists of three helices, wound upon as many radial cores, set at equal distances upon a central prism of the same number of sides. Through the central axis of this prism the shaft is placed longitudinally, and, as before stated, supported in bearings in the end caps of the motor. The outer or peripheral extremity of each of these cores is segmental in shape, coinciding in curve with the inner concave surfaces of the pole pieces between which it revolves. The helices are wound parallel with the axis of the armature as in the Siemens shuttle armature, and each is complete in itself. Similar ends of each helical wire are connected with the commutator segments, of which there is one for each helix; and the other similar ends are carried out to a common union, insulated from and carried upon the shaft.

It has been the aim of the inventor to design his motor on such mechanical lines as would

insure cheapness and simplicity of construction with least cost of maintenance. To this end the cylindrical form was adopted, as it furnishes bearings of the greatest solidity and protects completely the operative and vital parts of the motor, thus allowing of its use, without injury, in the most exposed situations. The division of the field-magnet coils into three helices for each field was adopted as the most likely way to prevent undue heating in the motor circuit, in addition to which the shortness of the cores abutting immediately upon the large surface of the outer shell furnishes, by conduction and radiation, a ready means for the dissipation of all such heat.

The polar armature was chosen by Mr. Edgerton on account of its ease of construction, and because the peripheral segments of the spools on which the helices are wound make it impossible for the motor, at its highest speed, to displace any of the wires by "tangential inertia"; further, because in the rise of temperature in

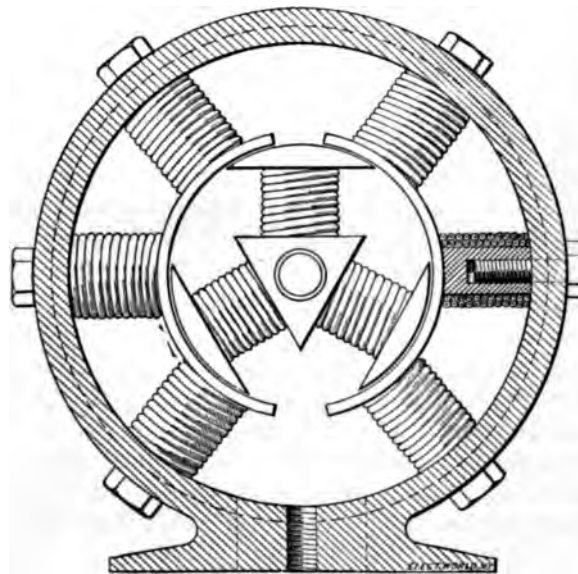


FIG. 191.—SECTIONAL VIEW OF EDGERTON MOTOR.

the motor due to flow of current, while in operation the coefficient of expansion is the same both in armature and field, which, of course, allows of the rotation of the armature in closer proximity to the pole pieces; and, lastly and principally, because, according to Mr.

Edgerton, the inductive action of the field is received first by the iron core and transferred through that to the wire, thus reducing the resistance of the armature circuit, due to counter-electromotive force.

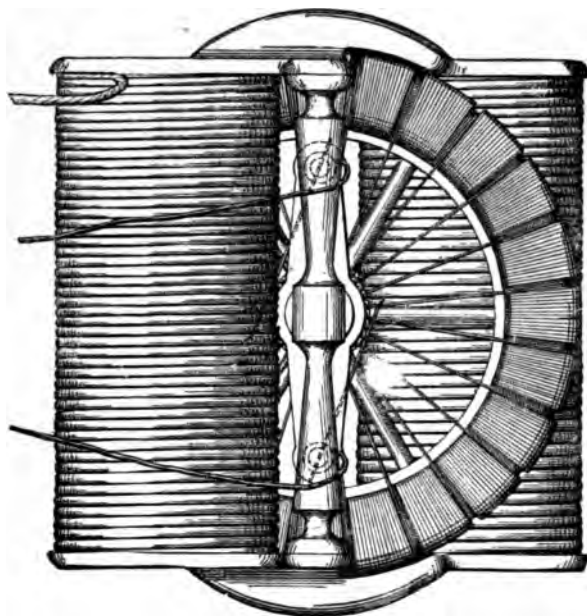


FIG. 192.—THE FISHER MOTOR.

The armature is connected in series between the fields in the small motors, although it is perfectly feasible to place it in a shunt. When the machine is coupled in series and in operation, the current is active at all times in two of the helices and momentarily in each revolution in all three.

In the smaller sizes, the speed of the motor is regulated by means of resistances included in the main circuit in the shunt around which the motor is placed. In the larger sizes, viz., from one horse power and over, a centrifugal governor is arranged for maintaining a uniform rate of speed. With this size also the armature and commutators are changed from three to five segments; while, in those still larger, provision is made for one brush only on the commutator, while the other brush is transferred to the insulated ring of the bobbin union. As all the armature bobbins are coupled in multiple arc with this ring, it results, as a matter of course, that, with the commutator slits cut diagonally, the sparking at the commutator is reduced to a minimum.

It has been the rule, as evidenced so often in the preceding pages, in the construction of

electric generators or motors, to so adjust the armature with respect to the field magnets that, in revolving, the bobbins would pass transversely through the field of force adjacent to one of the poles and then transversely through the field of force adjacent to the other pole. Recently, however, Mr. Frank E. Fisher, of the Detroit Electrical Works, has devised and patented a modification of this by locating the plane of revolution of the armature parallel to and between the two planes, each of which contains one of the field magnets. The motor is now being made by the Detroit Motor Company. The opposite ends of these field magnets are then united by a pole piece extending from one across to the other in such manner that instead of revolving through the field adjacent to the poles respectively the armature is caused to revolve within the plane containing the poles of the machine, so that the poles are opposite the periphery of the armature and diametrically opposite each other.

Our illustrations, Figs. 192 and 193, show the new design in elevation and in plan, and are so clear that no further description is deemed

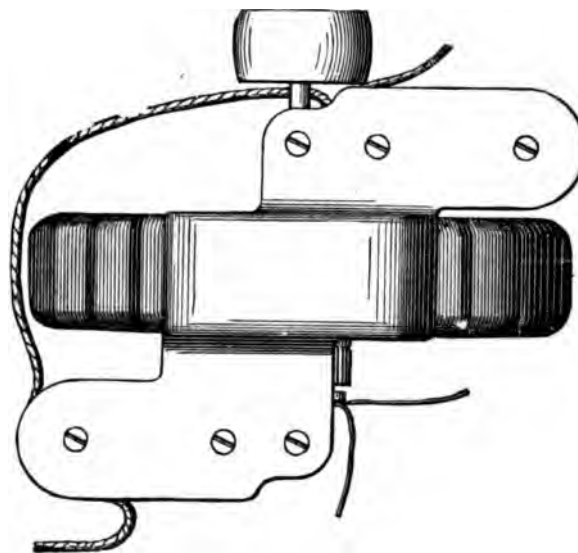


FIG. 193.—THE FISHER MOTOR.

necessary. According to Mr. Fisher, a machine, whether motor or dynamo, constructed in this manner operates with very much less resistance, and consequently delivers a greater effective force with the same impelling current. He attributes this increased efficiency to the fact that the construction is such that the

armature revolves diametrically between and in the plane containing the poles, instead of being obliged to cut through the plane transversely. Mr. Fisher, who has of late done considerable studying on the motor question, is also of the opinion that a beneficial effect in lessening the resistance to the revolution of the armature is obtained by the location of the armature with respect to the poles, so that its bobbins shall have a motion first transversely from end to end of one magnet in a direction across or through the planes of its successive convolutions of wire, and then in like manner from end to end of the other field magnet.

A patent issued recently to Mr. Elias E. Ries, of Baltimore, for an improvement in electrical railways, is of timely interest, as bearing upon the development and extension of electric street car lines.

In populated cities, as is well known, it is necessary that the conductors employed to convey the electric current to the motor cars should be carried in an underground conduit, extending along the line of the railway. As these conductors are necessarily naked or partially exposed, in order to permit of contact being made therewith by the current-collecting devices on the motor cars, one of the chief difficulties to overcome is that of maintaining proper drainage facilities and preventing water from coming in contact with the conductors at low-lying portions of the roadway, subject to such an overflow as would occur in case of unusually heavy rains, or from the accumulation of water in the conduit arising from foreign matter in, or back flow through, the drainage outlets, etc.

Mr. Ries overcomes this objection in a simple and effective manner, so that portions of the conduit may be entirely flooded with water and the conductors therein completely submerged, without in the least interfering with the flow of current to the motors on other portions of the line. This result is accomplished by automatically cutting out, under the influence of the rising water in the lowest portion of the submerged conduit section, that portion of the conduit conductors belonging to the submerged section, and shunting the current through insulated loop conductors or cables that bridge the section cut out and connect the main conductors at both sides thereof. The conductors in the submerged conduit section will remain cut out of circuit as long as the water in the conduit is of sufficient height to come in contact therewith; consequently, no escape of current from them can take place. Means—such as secondary batteries—are provided for automatically propelling the motor cars across the low-lying section when the conductors are cut out, so that it will be seen that this device renders underground electric-railway conduits perfectly practicable, even in the most unfavorable localities, and goes to settle once for all the vexed question of insulation, but permits the successful use of a shallow conduit under conditions where, without this device, a much deeper one might prove entirely incapable of protecting the conductors carried by it.

This patent also describes a number of important modifications, and forms part of a system of electrical railways now in process of development.

APPENDIX A.

THE OPERATION OF MOTORS FROM ELECTRIC LIGHT AND POWER STATIONS.*

WHEN I find that more than one hundred electric light companies have the words "and power" in their titles, I come to the conclusion that they mean something by it, and the drift of the paper I had the honor to present, as a proxy, before the Association last February on motors, was that it is worth the while of electric light men to pay attention to the questions involved in the distribution of power electrically. The "faith" exhibited by a high-sounding corporate name can be profitably seconded by "works." Electric light men, for the reason that they, more than any others, are familiar with the modern problems of heavy electrical engineering, are the best qualified to introduce electric motors to public notice, and the further I investigate this subject the more deeply do I become convinced that there is hardly a locality where an electric light plant exists in which also electric motors cannot be installed remuneratively.

At the present time, the feeling with regard to motors is in many quarters so sanguine that it amounts to a "boom." Now "booms" are just as bad in their way as inflation of the currency, or any abnormal display of high spirits and strong imagination. But in the case of electric motors, the "boom," if there be one, has been slightly delayed. Historically, the electric motor anticipates in practice the electric telegraph, the electric light, the telephone, and the storage battery, yet to-day it has less importance than any of these, except possibly the last. I venture the opinion that in the near future the relative prominence of these applications will be somewhat changed. Perhaps it is well that the greater perfection of

* A paper read by Mr. T. C. Martin before the National Electric Light Association, Detroit, September 2, 1886.

the electric motor has been delayed, and even to-day is tardy. Its ultimate success has depended upon improvements in primary batteries, in secondary batteries, in dynamos, steam engines, boilers, and furnaces burning cheap fuel, upon improvements in wires and in line construction, upon the development of modern ideas of urban convenience, and in no small degree upon the multiplication of minor industries requiring power minutely subdivided, yet, like the Eastern genii, ready at beck and call. I might, indeed, assert that the electric motor had, for its full fruition, to await the growth of the modern idea of centralization, through whose influence we are led to depend on central stations and agencies for light, time, and heat, ice, water, and air, "patent inside" newspapers, associated press despatches, and almost every one of the comforts, conveniences, and nuisances specially distinguishing modern life from that of the days gone by. The electric motor is the latest, in many respects the most effective realization of the idea of centralizing productive effort with the view of gaining the greatest good for the largest number, yet leaving the individual a larger freedom than he ever enjoyed before. Mr. Henry George, the economist and social reformer, told me the other day that he feared electricity would be monopolized like other forces, and that though the electric motor would enable manufacturing producers to work cheaply on a small scale and widely scattered, it could only mitigate the evils of the private ownership in land that now crowds our working population into dens and hives near their places of employment. I am a little more cheerful and optimistic than he. While I am not one of those who arouse Mr. Matthew Arnold's anger by looking upon railways, cheap postal service, and electrical ap-

plications as marks of the millennium, I do prize them, especially electricity, as means to the end of gratifying the instinct of man for expansion, and affording him the opportunities that enlarge and secure his existence.

That way lies the social philosophy of the electric motor, whose wires can be run through a key-hole, into a tenement or out through country districts, and whose uses are common to all in need of power. Now a few words on the practical side of the subject. At the present time, the application of the electric motor divides itself into two departments, both of interest to electric light men, that of street railways and that of industrial work. A brief glance may be taken at each department separately, and, first, at that of street railways. As nearly as I can estimate, with close figuring on each of the roads, over a million passengers have already been hauled by electric locomotives in America, while the number in Europe far exceeds that. Such a fact is significant in itself in these days of rapid change of system and greater attention to comfort in travel. Probably we shall not have to wait for an epizooty in the car stables before we see a very general adoption of electricity in the propulsion of street cars. The Baltimore Daft electric street railway, over which many of you travelled in heavy slush and rain last February, is now in its second year of operation, without any electrician in charge, and contemplating an extension. The cost of electric power per day is \$12, as compared with \$18 for horses under the old system; and the cost per passenger last year was .83 cent, or about half, as compared with 1.55 cents in 1884.

The Daft system is in use at Revere Beach, Mass., and is now being introduced on the street car lines at Los Angeles, Cal., and elsewhere. The Van Depoele system of electric locomotion is in use in, or under contract for, several cities, among which may be named Minneapolis; Montgomery, Ala.; Windsor, Ont.; Detroit; Scranton, Pa., and Appleton, Wis. The figures will, I hope, be presented by Mr. Van Depoele himself, showing results of great economy as compared with mule or horse-power traction. In Philadelphia, Mr. W. M. Schlesinger has a good system operating on a half-mile track, and one that will be introduced at more than one point early next year. The Bentley-Knight system that was successfully tried in Cleveland

last year, can now be seen in operation at the Providence Locomotive Works, Rhode Island. And last, though very far from least, is the system of Mr. Frank J. Sprague, who has worked out his inventions and plans with a thoroughness and ingenuity that must awaken admiration in every one. I am not at liberty just now to explain the details of the system; they will probably be made public in a short time.

To show what is thought of elevated electric railways, I may quote Prof. Henry Rowland, the distinguished physicist of Johns Hopkins University. As to this system he says: "Altogether there is no doubt in my mind that Mr. Sprague's method of working motors for electric railways is thoroughly scientific, and that it has many advantages from a practical point of view. It is also decidedly more economical than any other that has been brought to my notice, and will certainly accomplish what is required in such a case, namely, the moving of a train of cars from one station to another in the least time, with a given maximum speed, and with the greatest economy of power and least wear and tear of machinery." I should add that Mr. Daft is also resuming his work, with heavier motors, on the New York elevated roads.

Mr. Sprague has for some time past had a car propelled by his motor running on the Thirty-fourth street branch of the New York elevated railroad, ten blocks away from the generating station. I mention these facts because many minds are at work on electric street railway problems, because the enterprise will be carried out, and because electric light men operating large stations, as many of them now do, know that they can easily generate and handle the large currents necessary. In fact, if they will seize their opportunities, many of the street railways will soon be operated electrically by electric light men. The whole new motor business is legitimately theirs, just as the electric light field and that of telephony opened up new careers to telegraphers. In electricity, we rise on the stepping-stones of our old selves to greater things. Some electric light men will naturally say that they are at present as busy as they need be, and it is true that the electric light man has yet to be evolved who can say, with Walt Whitman, "I loaf, and invite my soul." Still, I think that most of you will in a

few years be interested directly in street-car operation.

The second department in which motors are being used to-day is the industrial; although, even already, the industrial work is subdividing itself. The number of small electric motors in use to-day industrially in this country may be put at certainly far beyond 5,000. Of the old, familiar Griscom motor, several hundreds have been put in use; of the Stockwell motor, about 1,000 have already been called for; Daft motors are in use in New York, Boston, Worcester, Providence, Coney Island, and other places. Sprague motors are running in New York, Chicago, Boston, Pittsburgh, Des Moines, Elgin, Oskaloosa, Shamokin, York, New Brunswick, Fall River, New Bedford, Milford, Taunton, and Lawrence, Mass.; and there are also a great many Brush, Baxter, Pendleton, Bergmann, Keegan, Edgerton, Reckenzaun, Ayrton and Perry, Diehl, Roberts, Crocker & Curtis, and other motors in use all over the country, on work of the most varying nature. A few exemplifications of their use by electric light companies will perhaps be interesting. In Philadelphia the Brush Company is running about 250 Stockwell motors and one one-horse-power motor. The small motors are chiefly on factory sewing machines, but some are on fans and jewellers' lathes. They are generally giving satisfaction, and if the company could only get its wires to the places wanting motors, the number in use would be quadrupled. Mr. M. D. Law, the electrician of the company, who has charge of this department, operates eighteen of the small motors with the power required for one arc light, if they all of them run together at one time; but in practice he has no trouble in running from thirty to forty with the same power, as they are never all on together. The charge for the current is \$5 per month for the first four motors and then \$1 per month for each additional motor. All motors are wisely sold outright, the company only renting the current for them. At the Brush-Swan station, Cheyenne, Wyo., Mr. E. P. Roberts is building his own motors and finding a wide variety of use for them. One runs an evening paper, another a gunsmith's lathe and emery grinder, and two others cut up sausage meat for butchers. In the case of the gunsmith, the charge is ten cents per hour per horse power. The motors are run from Brush storage batteries on the day

incandescent circuit, and at night from the dynamo, the potential being 100 volts. The Brush station at Baltimore has been putting out motors, chiefly of the Baxter and Edgerton types, quite extensively. The Baxter motor there has been running on a great variety of work, on arc circuits, with good profit, and is said to be very economical of power while regulating with the utmost closeness under all variations of load. At Germantown an Edgerton motor is running a Gordon press most successfully. In Detroit the Brush Company is also running several motors.

At Des Moines, Ia., the local Edison Company is running a number of Sprague motors. The motors there are sold outright and the current is generally charged per meter. One of these motors, of three horse power, is used in a livery stable to run the elevator for hoisting the buggies and hay, for pumping water, and for brushing down the horses. One runs a scissors-grinder's outfit, one a drug mill, one a polisher in a plating establishment, and, curiously, one the generator in the telephone exchange. Several elevators now run by water will have electric motors this fall. Mr. F. H. Whiting, the manager, says: "I think that the motors in reasonably large towns can be made to go a long way to the paying of running expenses of those stations that have to run all the time, as in the incandescent business."

At New Bedford, Mass., seven Sprague motors have already been installed within a short time by the local Edison Company, and are now used in silver-plating works, on ice cream freezers, on coffee grinders, on bookbinders' cutting-presses, on a hydro-extractor in dye works, and on a hair-picking machine. These motors earn easily altogether about \$40 a month, on the regular incandescent circuit, the current being supplied at lamp rates, one and one-fourth cents per sixteen candle power lamp hour, and measured by meter.

In Boston, the Sprague Company is running a large motor service on a circuit embracing a three-quarter mile radius from its station in Bumstead Court, the motors ranging in capacity from one-half horse power to seven and one-half horse power. To enumerate all the kinds of work done would be to mention most of the machines for small work heretofore driven by steam engines or foot power. The motors are sold outright to the customers, and

\$125 per horse power per annum is charged for the current or power service. For elevator work, there are special rates depending upon the average use by the consumer. The amount of average consumption is determined by ammeter and voltmeter, and from that determination a contract price is made. The intermittent use by the consumer is found to be an important factor in supplying power, as not more than thirty-seven per cent. of that sold is ever called for at one time, so that, allowing for the loss in transmission, at least double the engine service can be sold, provided the power is distributed in small quantities. From actual tests made by one company it appears that some few of the averages of power consumed run as low as fourteen and fifteen per cent., and Mr. Sprague tells me that the higher average of from thirty-three to thirty-seven per cent. will apply not only to small powers, but is absolutely true of large powers, such as forty, fifty, or one hundred horse, where a number of these are operating together from a central station.

As an evidence of the feeling in Boston on the subject of motors, I may mention that the Merchants' Electric Light and Power Company, running 800 Thomson-Houston arc lamps, has voted to adopt, and is now equipping for, the Sprague system. At Springfield, Mass., another actual electric power station will be established. The Springfield Steam Power Company, heretofore transmitting power by belting, shafting, and wire cables, has now decided to distribute power by means of electric current, as giving a better and more economical service, as well as increasing the distance at which it can work. The change is being carried out at the present hour.

In New York a great many Sprague motors are in use. A large number of Daft motors have been in operation there for a considerable length of time, and I know from actual personal inquiry and observation that you could not get

the customers to abandon the use of their motors. One instance deserves special mention. Mr. E. B. Stimpson, in Spruce street, well known as an inventor and manufacturer of fine machinery for the shoe and stationery trades, has for about a year been running three floors of his workshop with a Daft motor. Some of the machines belted to the shafting on the various floors are quite heavy—drills, lathes, planers, and the like; others are extremely fine and delicate; but for all of them, Mr. Stimpson tells me, the electric power has been sufficiently steady. He had formerly a ten-horse power vertical engine, with boiler on the top floor of his building, and had the usual trouble with engineers, coal, ashes, dust, oil, vibration, and great heat in summer. Now, in striking contrast, a little six horse power Daft motor stands on a small wooden base, close up against the disused boiler and engine, making so slight a noise that it in no way interrupts conversation. The motor runs the day through, and all the attention it gets is a very occasional visit and wipe on the commutator from a motor man, who also has charge of a number of other motors all around the neighborhood. Mr. Stimpson pays \$12 a week, and I doubt if there is a manufacturer in New York to-day better pleased with his power than is Mr. Stimpson with the electric motor he has been using so long and with such good results.

A great many motors to-day are operating very successfully with primary batteries, and that field will grow.

In the incandescent business, the plant must be kept running all the time, so that the consumer can always have his light when he wants it. Hence I look upon motors as the most important auxiliary to-day for incandescent lighting, and I think that in many an arc station, too, they will solve the financial problems of day lighting. But whether that be so or not, what I have said shows, I think, that the day of the electric motor is upon us.

APPENDIX B.

THE JULIEN ACCUMULATOR AND TRACTION SYSTEM.*

THERE is no question to-day more interesting to the electrician than, and hardly any so important to street railway companies and the urban public as, the application of electricity to the propulsion of tram-cars. A critical stage has been reached in the practical development of this latest field of applied electricity, when all that is offered to notice deserves close study. At the present moment, M. Ed. Julien, engineer and electrician of Brussels, is demonstrating in this city the merits of his system of electric traction, and it is arousing unusual attention. We deem it proper, therefore, to give a description, with illustrations, of this system, concerning which some of the foremost street railway men in America as well as in Europe entertain a very high opinion, one that they are preparing to give evidence of in employing the Julien cars on their respective roads.

At the outset, it may be remarked that M. Julien occupies in Belgium a position giving him no small authority in the matter of traction. Besides being himself familiar with tramway operation and conversant with all the needs of the industry, he has for several years devoted himself specially to the problems of electric traction, and more particularly to the use of accumulators for the purpose. As far back as 1881, he organized the *Compagnie l'Electrique* for introducing the Faure accumulators and the Brush electric light system in Belgium; and being thus one of the first to study practically and seriously the employment of accumulators on street cars, he is better able than many to appreciate the advantages, and to eliminate or minimize the inconveniences attaching to their use. At the time M. Julien began to experiment, the storage battery had fallen into a good deal of discredit

* *The Electrical World*, Nov. 20, 1886.

that was to a considerable extent justifiable, and that resulted from the instability of the battery. This condition of affairs, observed M. Julien, sprang from the production of the plates on a wrong principle, industrially speaking—that of the oxidation of the lead supporting the active material applied to its surface by whatever process, whether decomposition or addition. The result in either case was that when the plate was formed by the action of the current, the positive was more and more deeply oxidized, so that after a relatively short time, if the battery were put into continuously active service, the supporting substance was wholly transformed into peroxide, a material of little consistency or conductivity. In that state the battery was inert and useless, and it became evident that such conditions afforded no hope of profitable occupancy of any industrial field. And this may be said to be the consensus of opinion on the part of all the physicists who have studied the subject since the discovery of secondary batteries, that is to say, since the beginning of the century. Though of interest, it is not necessary for us to enter here into a description of the early efforts and attempts made to construct a practical storage battery, but on the contrary, we will proceed at once to describe the methods by which M. Julien has achieved success.

M. Julien has followed a principle directly opposite, it is believed, to that heretofore employed, at the same time taking advantage of what had been determined to be proper in the generation of secondary battery currents. After much laborious research, he recognized the fact that by combining different metals, such as lead, mercury, and antimony, in certain definite proportions, an inoxidizable alloy is formed which is found to be eminently adapted for use as supporting plates in storage batteries. At-

tempts had already been made to give the supporting plate greater consistency, and to that end Faure, and M. Julien, too, also added antimony to the lead from the beginning of their manufacture, but no attempt had been made to render the plate inoxidizable.

By means of the inoxidizable plate M. Julien has succeeded, it is thought, in removing the old objections to the storage battery, the plates remaining rigid and undergoing no deformation. The active material adheres perfectly to the metal plate, due principally to the nature of the alloy employed. The life of the

Duration of discharge, 6 hours 48 min.
 Final Electromotive force per cell, 1.89 volts.
 Average strength of discharge per
 kilogramme, 1.74 ampères.
 Energy given out per kilogramme, 8,600 kilogrammètres.
 Ampère-hours per kilogramme, . 11.83.

This showed a commercial efficiency of 80 per cent. when the discharge was stopped at the point where the cells had fallen to 1.89 volts electromotive force. It will also be noted (by converting into English measures) that the cells were capable of delivering about 5½ ampère-hours per pound of weight.

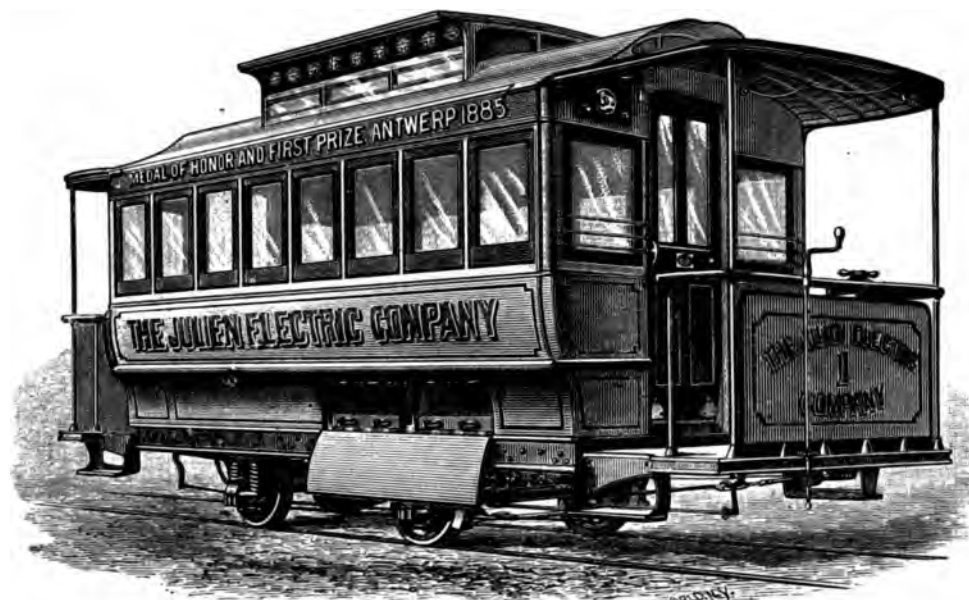


FIG. 1.—THE JULIEN ELECTRIC STREET CAR.

plates as demonstrated by several instances is a long one, and after nearly two years' use they show no deformation.

Some experiments recently made with the Julien cells by Professor Eric Gérard at the University of Liege, France, under the auspices of the International Commission of the late Antwerp Exhibition, show clearly the results obtained by M. Julien's improvements. The following table shows the result of a test made with twenty-four of the cells:

Duration of charge, 7 hours 33 min.
 Electromotive force per cell, . . . 2.35 volts.
 Average strength of current per
 kilogramme, 1.86 ampères.
 Energy absorbed per kilogramme, . 10,700 kilogrammètres.
 Ampère-hours per kilogramme, . 14.

The accompanying illustrations, Figs. 3 and 4, show the record of a test made with twenty-nine Julien cells furnished to the Edison Company of Paris. The curves were traced by a registering instrument designed by M. Huber for that purpose. The cells weighed forty kilogrammes each, and were charged at the rate of fifteen ampère-hours per kilogramme and gave at discharge 13½ ampère-hours, showing an efficiency of ninety per cent. The discharge lasted nearly thirty hours, during twenty-two of which no variation of current strength took place, with a fall in potential of only four volts.

As regards the life of the batteries already referred to above, it is interesting to note that for more than two years Prof. L. Nothomb, of the War School at Brussels, has lighted his

house by means of a battery of Julien cells, which are still in a perfect state. Our readers will also remember that after six months' service on the electric car at Antwerp, and also in the exhibition, the cells were pronounced by the jury testing them to be unchanged.

More than any other application, electric traction has exacted the employment of perfect accumulators. The constructors of secondary batteries have been aware of this fact, and hence, in all probability, it happens that this specific use has been so limited. It is impossi-

ble to attempt a traction system without batteries that can be depended upon. The work is the most exacting that a battery can be subjected to. The current drawn off varies every minute, and is always at a strength very high in view of the number of elements employed. The incessant shaking of the car is also a cause of rapid deterioration in ordinary electrodes in which the active material is not highly adhesive. It is necessary also that the battery should be extremely light and should require little attention. All these considerations have been borne in mind, and have, M. Julien thinks, been met in his system.

tramways with the Faure battery,—being the first known application of the kind, on tramways proper. The car then used differed very little from that now seen in New York. The main object of M. Julien, then as now, was, after having obtained the battery he sought, to get a practical car. In tramway exploitation, it is specially essential that the devices used shall be the simplest, as well as easy of manufacture. This double point M. Julien claims to have reached. Another objective point is the utilization of the existing rolling stock, and that he has also studied out successfully.



FIG. 2.—THE JULIEN ACCUMULATORS IN STREET CAR SERVICE.

The first experiments undertaken by M. Julien were made in June, 1881, on French

The car that is now in operation on the Eighth avenue road is, on a cursory glance, indistinguishable from any ordinary street car of the type familiar in New York streets, and capable of carrying from seventy to eighty people. It was built by John Stephenson for the Vienna Exposition of 1873, and thus by a strange and happy turn of events returns to the place of its departure after thirteen years absence. The batteries are placed under the benches; the motor and the running gear are placed beneath the car floor. Under each platform is a regulating apparatus controlled by a hand-lever covered by a circular box. All the mechanism has been devised so as to be easy of operation by men who have had neither electrical nor mechanical train-

ing; and this ensures the employment of men accustomed to the road and to street car work generally. The operating parts comprise simply the motor, which is connected by rope gearing

are not at liberty to enter just now. It may, however, be said that, as a whole, *as a system*, the apparatus is well adapted to the ends it serves. Nothing has been left undone, and all the parts work automatically, rapidly and economically.

The car is well lighted by two incandescent lamps fed by the batteries. The brake is worked by hand, M. Julien considering it unwise to add complication or use up current, by resorting to electricity in this item.

When the car leaves the stable, the recharging of the batteries is effected on a series of benches, on each side of the indoor tracks, as shown in Figs. 5 and 6. The exchange of a charged for an exhausted battery does not occupy more than four or five minutes, and as they are pushed into place, the cells automatically make connection.

Our readers well remember that a highly favorable and flattering report was made relative to the Julien car by the special jury at the Antwerp Exhibition in 1885, when it achieved a notable triumph over several systems and carried off the prize, both on the ground of efficiency and on that of economy. The report

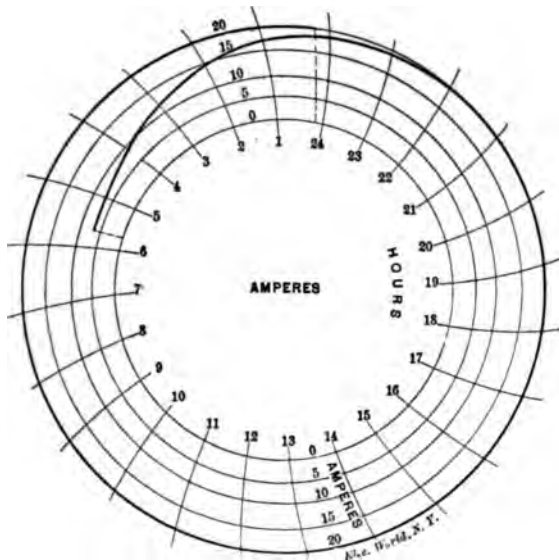


FIG. 3.

to a countershaft, and this in turn is connected with the driving axles by a link-chain of special contrivance. The armature makes from 800 to 900 revolutions per minute, while the wheels make 100—at normal speed. The car is started up, by turning the lever, without the slightest shock. The movement is, in fact, remarkably smooth and pleasant, and the car can be stopped instantaneously. The rate of speed is controlled both by the number of elements and by manipulation of the mechanism itself. It is noteworthy that M. Julien depends in no way upon artificial resistances. The rapidity of movement is controlled by the batteries, and full speed, half speed, full stop, and reverse motion are all obtained by the merest turn of the lever. To the regulator are brought the connections of all the sections of the battery, working alternatively in series and in parallel. All the cells discharge uniformly, and can, therefore, be recharged together. Without this provision, the charging of a large number of batteries would be a matter of enormous complication, if not an impossibility, in a regular service. The motor has an ingenious commutator, rendering attendance and inspection very easy, as well as a simple method of changing the rate of armature rotation. Into details we

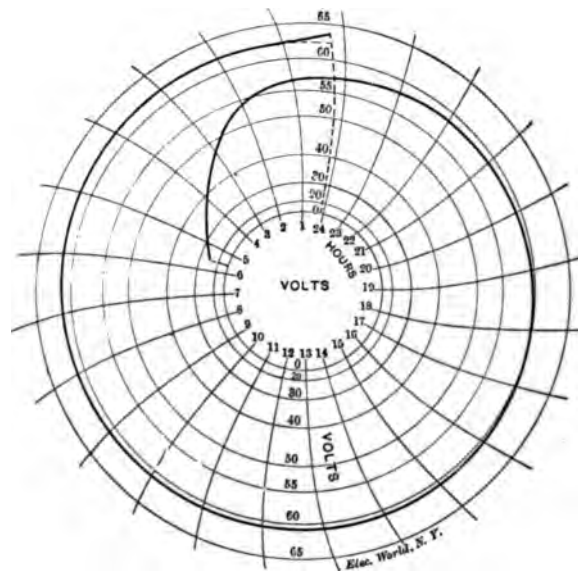


FIG. 4.

of the jury was noticed at great length in *The Electrical World* of March 20, 1886. The jury of ten comprised representatives of the governments of France, England, Germany and Belgium, as well as a number of experts. The

competition lasted from May 3 to Oct. 31, 1885, and was participated in by the Julien car, the Krauss locomotive engine separated from the carriage, the Wilkinson locomotive, also sepa-

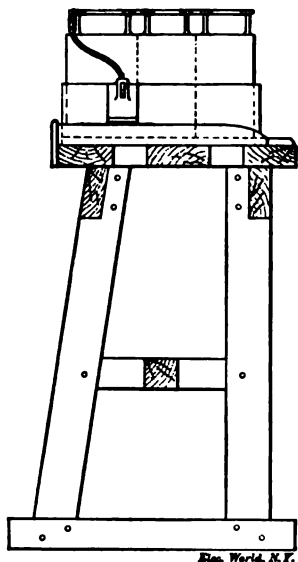


FIG. 5.

rated, the Rowan engine and carriage combined, and the Beaumont compressed air engine. The report of the jury covered twenty-three points of comparison, embracing the whole range of operation, and was favorable to the electric car in a most remarkable and significant manner. It was especially noted that the accumulators had been in use prior to the trial, and that at the end of the competition they showed no sign of deformation, deterioration or polarization. The weight of the car was 5,654 lbs.; the weight of the accumulators was 2,460 lbs., and the weight of the machinery was 1,232 lbs. The car could carry fourteen passengers inside and twenty outside.

The jury also made special and appropriate note of the fact that the dynamo used for charging the accumulators had an efficiency of only sixty-one per cent., a figure far below the average with modern machines, American dynamos attaining over ninety per cent.

M. Julien calculates that for a daily run of 100 kilometres, or about sixty-five miles, at the rate of six and one-half miles per hour, it would require about seven and one-half horse-power per car when run singly, and only ten horse-power (*i. e.*, five horse-power for each) when two cars are run together at the same speed.

From this the coal consumption will be easily computable. On the most liberal basis of calculation, the cost with accumulators appears to be far below two-thirds that of cable or horse traction.

So far, as regards the advantage to the street car company. There are also great and direct advantages to the public in the use of the electric car as compared with horses. The service is more expeditious; the streets are less crowded and much cleaner; the motion is easier, and the cars are better lighted. Large stables no longer spread over large blocks required for human occupancy, and the whole change is in the direction of improving the condition of the city. Now that the first steps have been taken, the revolution, for it is nothing else, in methods of urban travel, will go on with tremendous rapidity.

It is not alone in Antwerp that M. Julien has given evidence of the value of his system. In Paris he has cars running daily and regularly between the Palais de l'Industrie and the Place de la Concorde. The awarding committee of the International Exposition of Industrial Arts and Sciences has just given him a diploma of honor, in keeping with that conferred in Belgium. At Hamburg, M. Huber, who holds the right to use

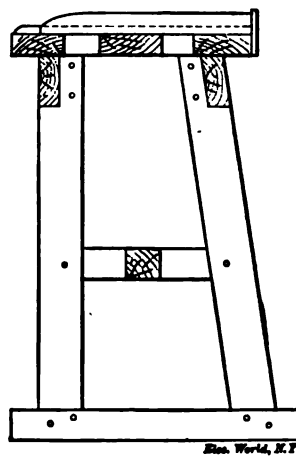


FIG. 6.

the Julien system in Germany, has been running a service since the month of April last, and the two cars have up to date required no repairs. At Brussels, the tramway company is now engaged in equipping to operate one of its lines by the Julien system, after a thoroughly satisfactory trial of two years. The confidence

of local capital in the change has been exemplified in the quotations of the stock. Negotiations for control of the system are, it is stated, now pending in London, Paris, and Vienna, as well as for Italy, Spain, and Portugal. The Belgian papers to hand report that Mr. Hargreaves, a Brazilian engineer, who has acquired the rights for South America, is now organizing a staff in Brussels and building his cars to serve as models. The movement is evidently a general one, and deserves attention for that, if for no other reason. In New York a corporation has been formed under the name of the Julien Electric Company, to extend the use of the system all over the United States, and it has now, under the personal supervision of M. Julien, inaugurated the operation of street cars with accumulators, after the manner illustrated by the car described above.

A subject of this nature demands very full treatment, and although we have now de-

voted considerable space to it, approaching developments will, without doubt, necessitate further and even more exhaustive discussion.

Fig. 1 shows the car now running in New York. Fig. 2 shows a set of accumulators, on the receiving bench in the car stables. Fig. 6 shows a bench without accumulators, and Fig. 5 a bench on which a set has been placed. It will be seen at a glance that the change from horses to electricity, as motive power, can be progressive, and therefore far from costly. Thus on a road with one hundred cars, ten can be "changed over" and equipped for the system, and the price for which the eighty or one hundred horses rendered unnecessary can be sold will more than cover the initial outlay. This is an important consideration with many, and will have its influence in all probability in bringing about the change more quickly.

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